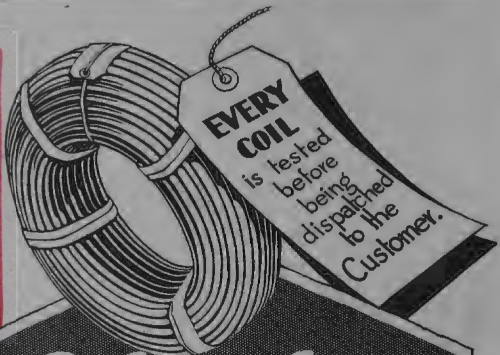
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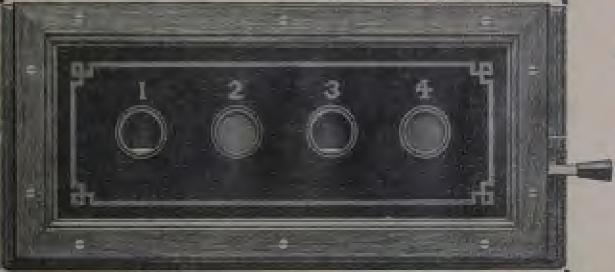
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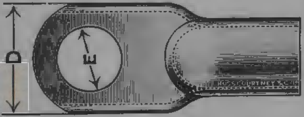
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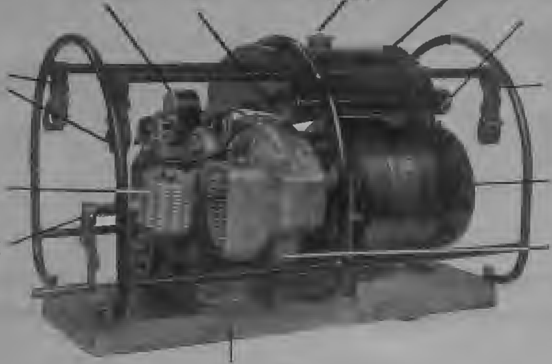
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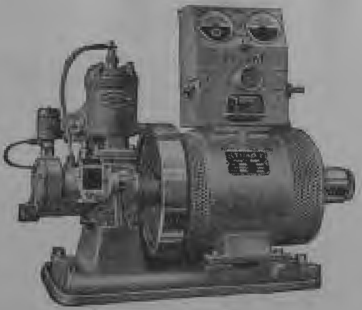

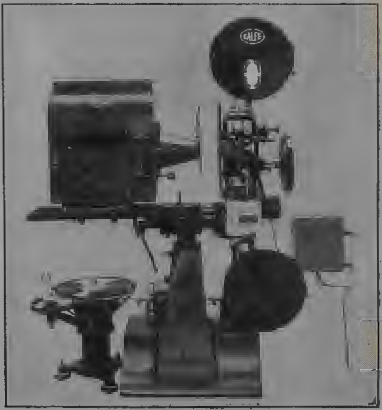
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1931

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INTERNATIONAL SYMBOLS USED IN ELECTRICAL WORK.

Length	l
Mass	m
Time	t
Energy	W
Power	P
Efficiency	η
Number of revolutions in unit time	n
Angular velocity $\left(\frac{2\pi}{t}\right)$	ω
Frequency	f
Phase displacement angle	ϕ
Electro-motive force	E
Current	I
Resistance	R
Specific resistance or resistivity	ρ
Maximum value of a variable e.m.f.	E_m
Instantaneous value of a variable e.m.f.	e or E_t
Maximum value of a variable current	I_m
Instantaneous value of a variable current	i or I_t
Temperature coefficient	α
Quantity of electricity	Q
Difference of potential	V
Capacitance	C
Self-inductance	L
Mutual inductance	M
Reactance	X
Impedance	Z
Reluctance	S
Magnetic flux	Φ
Flux density	B
Magnetizing force or magnetic field intensity in air	H
Permeability	μ

Abbreviations for Names of Electrical Unit to be Employed Only After Numerical Values.

Ampère	A
Volt	V
Ohm	O or Ω
Coulomb	C
Joule	J
Watt	W
Farad	F
Henry	H

Watt hour	Wh
Volt ampère	VA
Ampère hour	Ah
Milliampère	mA
Millivolt	mV
Kilowatt	kW
Kilovolt ampère	kVA
Kilowatt hour	kWh
Candle power	c.p.
Foot candle	f.c.
Megohm	MO or MΩ
Micro-farad	μF

In accordance with report of the International Electrotechnical Commission, 1920.

ABBREVIATIONS.

D.C.	Direct Current.
A.C.	Alternating Current.
P.F.	Power Factor.
L.V.	Low Voltage.
M.V.	Medium Voltage.
H.V.	High Voltage.
E.H.V.	Extra High Voltage.
C.R.	Conductivity Resistance.
I.R.	Insulation Resistance.
V.I.R.	Vulcanized India Rubber.
T.R.S.	Tough Rubber Sheathed.
p.i., l.c. & a.	Paper Insulated, Lead Covered and Armoured.
S.W.G.	Standard Wire Gauge.
B.Th.U.	British Thermal Unit.
m.s.c.p.	Mean Spherical Candle Power.
E.C.	Electricity Commissioners.
H.O.	Home Office.
P.O.	Post Office.
R.E.S.	Royal Engineer Services.
G.D.E.S.	Government Department Electrical Specification.
D.W.S.S.	Director of Works Standard Specification.
D.W.C.C.	Director of Works Contract Circular.
I.E.E.	Institution of Electrical Engineers.
I.E.C.	International Electrotechnical Commission.
B.S.S.	British Standard Specification.
B.E.S.A.	British Engineering Standards Association.
E.L.M.A.	Electric Lamp Manufacturers' Association.
B.E.A.I.R.A.	British Electrical and Allied Industries Research Association.

Military Engineering
Vol. X.

ELECTRICAL ENGINEERING.

PART I.—GENERATION, TRANSMISSION, AND DISTRIBUTION.

CHAPTER I.

POWER STATIONS.

1. *Introductory.*

It is proposed in this chapter to consider the various points which require investigation when the military engineer is called upon to prepare a scheme for the supply of electrical energy to a group of buildings or a small area. The actual details of a big scheme must necessarily be the work of a specialist.

As is to be expected, conflicting requirements are practically unavoidable, and experience is needed to ensure a satisfactory compromise. All that will be attempted is to discuss the various ways of dealing with the problem of the *supply* of power and the different points connected therewith, apart from the questions of transmission and distribution (dealt with in Chaps. III and IV).

2. *Source of supply.*

1. Before any scheme can be prepared, it is essential to consider the following points :—

- i. Amount of power required.
- ii. Source of power.
- iii. Cost.

(i) and (ii) are naturally to a large extent inseparable, though circumstances may arise to increase the importance of one or the other. For instance, it would be advisable to ascertain how much power can be obtained, and then to decide whether this power can be made to suffice for the load in question. In any case, a rough approximation of the probable maximum load is desirable first.

Power to meet the new load may be obtained in any one of the following ways, or possibly in two together :—

- i. Existing supply, as an additional load, or a new bulk supply.
- ii. Water power.
- iii. Heat engines—(*a*) steam, (*b*) internal combustion.

2. **Existing supply.**—Of the above, the first is the simplest, and possesses the obvious advantages of eliminating the personnel required to run a new power station and of avoiding the expenditure of capital in the building thereof. In addition, there will be no delay in the supply of the power, as would be the case should a special station have to be built for the load.

Although, in practice, it will very seldom be found economical to provide a generating station if a bulk supply is available in the vicinity, other considerations may render necessary an independent source of supply under military control. When such special circumstances do not exist, a very careful estimate of the capital expenditure, interest and depreciation, maintenance of plant, and generating costs of an independent station, as compared with the cost of supply only from an existing station, should be prepared before it is recommended for adoption.

In Great Britain special circumstances exist.

The Electricity Act of 1926 set up a **Central Electricity Board** with the primary object of making electricity available as cheaply as possible throughout the whole country. A network of **132kV** and lower voltage transmission lines are to be erected, and will supply distribution schemes at lower voltages. Where possible a bulk supply should be obtained from one of these.

The rival possibilities should, however, in all cases be compared with the cost of bulk supply.

In some circumstances it may still prove advantageous to generate privately :—

(1) Where the load is small, remote from a distribution line and oil engines can be used.

(2) Where coal is cheap, and there is a use for low-pressure heat, in the form of either steam or hot water. Condensing steam plant may be used and bled near the low-pressure end, or final exhaust used as required.

(3) Where water power is close at hand and can be harnessed with small capital expenditure.

3. **Water power.**—The employment of water power, when available, would appear, at first sight, to be advantageous, because of the elimination of the fuel bill, but on closer investigation it is frequently found to be unsound financially. This is generally due to two causes : firstly, that it is unusual to find a sufficient supply of water power near the place where it is required, and, secondly, that the necessary collecting and restraining devices and pipe-lines are expensive, resulting in a crippling interest charge on the undertaking. For these reasons it is usually more economical to generate the power

by heat engines near the load rather than by water engines at a distance.

Possibilities of drought have to be considered, and in this connection it is as well to bear in mind the large quantity of water which is required. Taking water turbine efficiency as 75 per cent., one cubic foot per second is required to give 0·85 B.H.P. per 10 feet head.

4. **Heat engines.**—In the case of heat engines, the choice has to be made between *steam* and some form of *internal combustion* (I.C.) engine.

In military work a very important factor is the personnel available, For efficient and economical operation it is highly desirable that changes in power-station staff should be as infrequent as possible, and in the case of **Diesel air blast injection engines** a **high degree of skill is necessary,** particularly for maintenance. The personnel normally obtainable in the service, however, do not usually possess experience in Diesel and gas engine plant; facilities for training in their operation are scanty, and frequent changes of staff appear inevitable. Consequently there is, to start with, a balance of advantage in favour of the cold-starter, solid injection, or one of the other forms of oil engine.

There are, however, other points to be considered, viz., **the size of the undertaking** and **the steadiness of the load.** For small installations, such as in coast defence searchlight work and for portable plant in the field, where both the total power and the size of the units are small and the load is intermittent, I.C. engines are undoubtedly superior, since capital costs, running costs (including stand-by losses), and the floor space required are all less than in the case of the steam plant.

As the size of the undertaking increases, and as the station becomes more permanent in nature, with a greater likelihood of being able to obtain skilled and unchanging personnel, the case for the steam engine becomes better. Although its overall efficiency, fuel to fly-wheel, seldom reaches 16 per cent., whereas that of the best of the I.C. engines is sometimes as high as 30 per cent., the relative cost of fuel renders the discrepancy much less marked than would appear at first sight. Stand-by losses and time and fuel required for steam raising become less as the hours of running per diem and running days per annum increase, and tend, therefore, to put the steam engine more on an equality with the I.C. engine, where these factors, at any rate in the case of the oil engine, are practically non-existent. As the size of the plant and units further increases, steam becomes paramount, owing to the difficulties encountered in making I.C. engine units in large sizes.

Apart from the question of size, steam possesses the following advantages :—

i. Absence of noise, vibration, and offensive smell.
ii. Capacity for overloads.
iii. Regular turning effort.
iv. Closer governing, which is of great importance when running alternators in parallel.
v. Reliability, in spite of the very large strides which have been made recently in this direction by the makers of I.C. engines.

I.C. engines, on the other hand, are more efficient and, in the smaller sizes especially, less costly ; they require less personnel and floor space, fewer auxiliaries, and considerably less water. They can be started much more quickly than steam engines, but respond badly to overloads.

Steam engines may be either reciprocating or turbine. The latter are, as a rule, used to drive the larger electrical generators.

The consumption per **kWh** of high-speed reciprocating condensing steam engines, using unsuperheated steam, ranges from 20 lb. of steam or about 4 lb. of coal of average calorific value (12,500 B.Th.U.) upwards, a fair figure for a **150kW** generating set being about 25 lb. of steam and about 5 lb. of coal per **kWh.**

The absolute minimum consumption of turbines may be taken as about 10 lb. of steam per **kWh.**

Very compact turbo-generating sets in sizes from **250kW** upwards are now obtainable. These sets are entirely self-contained with condenser and all other auxiliaries. As a result erection is very simple, and elaborate foundations unnecessary. Such sets may be started rapidly without exhausting to atmosphere, and without any auxiliary electric supply. Their efficiency probably approximates to that of reciprocating engines of the same size.

I.C. engines may use either gas or oil as fuel. Gas engines are occasionally more suitable than oil engines, and in such cases the fuel consists generally of what is known as producer gas, which is formed by the decomposition of carbon (in the form of coke or coal) and water. The combustible products consist chiefly of carbon monoxide and hydrogen. The fuel in the smaller sizes of engine is generally formed from anthracite, and the consumption is about 120 cub. ft. of gas or 1⅛ lb. of anthracite coal per **kWh.** This form of engine requires about 1 to 1½ gallons of water per unit for washing the gas, in addition to that necessary for cooling purposes. This type of plant, owing to its complexity and unsuitability for field use, will seldom, however, be met with in military service, and it is unlikely that military personnel with the requisite knowledge will be obtainable.

The oil engine employs as fuel all kinds of oil, from residual petroleum to the lighter hydrocarbons, such as petrol. Low compression high-speed paraffin engines, usually starting on petrol, are not, as a rule, suitable for units over **25kW**, but for very small generators of less than this output they are undoubtedly the simplest prime mover. They are very portable and can be run without foundations, but are not recommended for permanent or semi-permanent installations. They are expensive to run, and they are not suitable for running for long periods on end. The hot-bulb engine and the cold-starter can be obtained in sizes as low as 4 H.P. The fuel consumption of oil engines, at full load, varies between 0·5 lb. and 1·2 lb. per **kWh,** the former figure being attainable by the air blast and solid injection cold-starter engines using heavy fuel oil; the average paraffin consumption of a 15**kW** set at full load is 1·0 lb. per unit.

Generally speaking, except as an addition to existing steam machinery, it would be cheaper, both in first and running costs, to install an I.C. plant for units below 200**kW.** For units of from **20kW** to **500kW** solid injection cold-starting oil engines can be recommended. This type of prime mover is cheaper, and requires less skill to run and maintain than steam plant of the same capacity; a smaller personnel is required, and repairs are less difficult, as there are no boilers. Also the installation of machines of this type will enable military personnel to be trained—and obtain practice in peace-time with the plant which they will probably be called upon to run on active service.

5. Summary of foregoing.—*Existing supply.* Use only when separate generation will cost more than purchase of energy.

Water power. Can only be used economically where the quantity of power available is constant and sufficient throughout the year, and initial cost of restraining devices, &c., is small.

Steam power.

i. Large premises.
ii. Fuel transport difficulty; must be near a road, railway, or canal.
iii. Good water supply necessary.
iv. No noise, vibration, smell, or gas.
v. Regular turning moment, less wear on bearings.
vi. Greater reliability than I.C.
vii. Speed regulation good.
viii. Large units made.
ix. Unsuitable for intermittent work.
x. Very economical when exhaust steam can be utilized.

I.C. engines.

- i. Small space.
- ii. Easy fuel transport.
- iii. Small water supply.
- iv. Few auxiliaries.
- v. Small trained personnel, easily obtainable.
- vi. Respond badly to overload.
- vii. Poor governing properties.
- viii. Suitable for intermittent work.
- ix. Repairs less difficult than with steam plant.

3. *Type of current.*

1. The question of what type of current to generate, viz., A.C. or D.C., can be best decided by considering the relative merits of each.

The primary advantage of A.C., from a distribution point of view, is the ease with which it can be generated at high voltage, and subsequently transformed to low voltage suitable for lamps and other consuming devices. Such a system implies low copper costs for the main feeders, and is of necessity employed for central power stations supplying loads at considerable distances. As the load approaches nearer to the generating station, this advantage gradually disappears, and the choice has then to be made merely from the point of view of the consuming devices.

2. The following are the chief points in favour of either type :—

Direct current.

- i. More suitable for motors which require :—
  - (*a*) Large starting torque.
  - (*b*) Variable speed (but *see* Chap. XIII).
- ii. Generators are easier to operate in parallel, particularly if driven by I.C. engines.
- iii. More suitable for arc lamps, and the only type practically possible for coast defence searchlights.
- iv. Accumulators can be employed, which is of great importance for Service purposes, where it is very seldom desirable to run the machines for the whole 24 hours.
- v. More satisfactory at present for the supply of fans and punkahs.
- vi. More suitable for welding, as there is less danger from shock.

Alternating current.

- i. Voltage can be varied by transformers containing no moving parts and requiring little attention. Therefore energy can be transmitted economically at high voltage and simply and efficiently transformed for distribution at low voltage.

ii. Large units can be made; this will only become a consideration over about 1,000kW, and will rarely concern the military engineer.

iii. More efficient and cheaper generators.

iv. Simpler and cheaper motors with no moving contacts, at any rate in the smaller sizes.

v. Little danger of electrolysis in cables.

The normal metal filament incandescent lamp is as suitable for one type of current as for the other.

4. *Choice of site.*

1. So many considerations are involved under this head that the site finally chosen will in nearly every case be a matter of compromise.

2. The site of a water-power station is practically fixed at the outset, for it must be very near the source of power in order to reduce the cost of the water distribution workings.

3. In the case of a site for a heat-engine station the following are the main points to be considered :—

i. *Distribution of load.*—The station should be near the *centre of gravity of the load*, to reduce distribution and cable costs to a minimum. Probable extensions are of great importance in determining this point.

ii. *Facilities for the supply of fuel and stores.*—The larger the station the more important does this point become. With a small undertaking a fair approach road for vehicles would suffice, while for a very large one it would be a paying proposition to construct a railway siding or canal.

iii. *Existing interests.*—It must be remembered that occupiers of adjacent land have certain rights and can enforce attention to their interests. The vibration and noise inseparable from most I.C. engines may constitute a serious nuisance; cases are on record of an enforced installation of steam turbines on account of their smooth and silent running, when some other form of prime mover would have been more suitable from an engineering point of view. Not only the form of plant installed but also the actual siting of the station may have to be modified from this cause.

iv. *Water supply.*—This is naturally of considerable importance in any but the smallest undertakings. Water is necessary for make-up boiler-feed, for condensing purposes in the case of steam, and for cooling and gas-washing in the case of I.C. engines. The supply of condenser cooling water is often a serious question, and many devices are employed to reduce the quantity to a minimum where water is scarce. To run the engines non-condensing is most undesirable, though it has been done where other considerations have forced the neglect of the question of water supply. The neighbourhood of rivers, canals, and the sea is naturally sought where the power house is large.

v. *Foundations.*—This question is so obvious that it is in danger of being overlooked, and cases have occurred where the heavier portions of buildings, such as chimneys, erected on unstable foundations have settled so badly as to become unsafe and to need entire re-erection.

vi. *Cost of land.*—Cases may occur, especially in large towns, where the cost of land is prohibitive and overrules every other consideration. In such circumstances the power station will have to be situated some distance away, and, consequently, the power must be generated at a high voltage and transmitted to transforming sub-stations in the area of supply.

5. *Auxiliaries and efficiency.*

1. In every power station allowance must be made for power absorbed in the station itself. This power is necessary for driving the various machines which are mere adjuncts to the main generating units. Such auxiliaries, in the case of steam engines, include boiler feed pumps, condenser, air and circulating pumps, and, in large stations, many other refinements, such as stoking and coal-conveying machinery, pumps for raising condensed steam from the condenser hot-well to the boiler feed tank, station hoists and cranes, economizer motors, switch motors, &c. I.C. engine stations require fewer auxiliaries, the additional plant required being the fans for supplying large pressure-fed gas producers and, in the case of air blast and solid injection heavy oil engines, air compressors for fuel injection and starting purposes; cooling water pump motors, oil purifier motors, and in some cases fuel pump motors; with air blast injection engines the compressors are, however, really part of the engines, and the power required to drive them is considered in the B.H.P. rating of the engine.

2. Auxiliaries in a steam-driven electric station are driven

either by steam or electric motors, the consumption of the former being some 10 per cent. greater than that of the latter. The power required will be approximately 5 per cent. of the amount installed in large stations and about 8 per cent. in small, made up as follows :—

Auxiliaries.	Large station (3,000kW).	Small station (250kW).
	per cent.	per cent.
Boiler feed	1·5	1·5
Condensers	2·6	3·7
Exciters	0·5	2·6
Oil pumps, &c.	0·6	0·6
Total	5·2	8·4

For example *see* Pl. **2**. This plate gives a typical load curve of a 6,000kW station on a particular day, and it will be seen that the units used in the station on that day were 5·24 per cent. of the total units generated.

Station lighting must, of course, be provided for, and be considered as non-productive power absorbed in the station.

3. Little of the potential energy of the coal is available for distribution as electrical energy at power station bus-bars. In practice, the percentage very seldom reaches 15 even in very large stations, and in small ones, under very unfavourable conditions of load, may fall to 3 or 2.

Well over 50 per cent. of this loss is accounted for in the heat carried off by the condenser cooling water, the function of which is to abstract the latent heat from the exhaust steam and convert it to water at approximately the same temperature. Flue gases, radiation, and machine losses are responsible for the remainder.

4. As regards the last point, *i.e.*, machine losses, the station efficiency will naturally suffer if the generators are habitually operated at light loads, since the bulk of the energy will be employed in overcoming the frictional resistances of the machines. As the load on the generators rises, the power required to turn them round will become a smaller proportion of the total, since at a given speed the machines require the same power to turn them round irrespective of the load; that is, the generator efficiency rises as the output increases, the losses becoming a smaller proportion of the output.

This question of efficiency has an important bearing on the design of the station and the number of units installed, the object being to run any machine as near full load as possible for as long a time as possible.

6. *Load characteristics.*

1. **Demand factor.**—It is evident that the maximum output of all the machines installed in a central power station need not amount to the gross aggregate power required by all the consuming devices which are supplied by it. In the first place, it will very rarely happen that any consumer will want the maximum power for *all* his consuming devices at the same time, *i.e.*, his maximum demand will be something less that his total connected load. The ratio of the actual maximum demand to the total connected load is known as the *demand factor*, and is usually expressed as a percentage; it may be applied to a system, to a group of consumers, or to an individual consumer, but, except in the case of a single consumer, the consideration of the diversity factor (*see* next para.) is also involved.

In the Electricity Supply Act, 1926, the **Station Maximum Demand** is defined as "twice the number of units of electricity supplied from the generating station during any consecutive thirty minutes."

The maximum demand of a consumer may be obtained either from actual observation, *i.e.*, measurement with maximum-demand indicators or, in the case of a new consumer, by estimation. The usual practice where two part tariffs are in force is to have an integrating meter which resets itself at zero every fifteen or thirty minutes, and has a hand which records the maximum reached during any one period. For purely lighting loads, it may be taken that the demand factor will be between 40 and 80 per cent., though in large residences, with more than 1·5**kW** of connected load, it might well be less than 40 per cent., and in fully-occupied barracks, where due care in the exercise of economy is not observed, the figure of 80 per cent. might be exceeded. In the case of combined power and lighting loads, a demand factor of 80 per cent. will seldom be reached, whilst where motors only are concerned the figure will vary from about 50 per cent. for 6 to 10 large machines to about 75 per cent. for one small machine.

2. **Diversity factor.**—In the second place, it is very unlikely that the maximum demands of a group of consumers will occur at the same time. As an extreme example, the case of a large central station supplying power to a number of large manufacturing concerns may be quoted; in such a case, the total power demanded may be as low as 20 per cent. of the aggregate full-load rated power of all the motors supplied by the system.

This consideration leads to a definition of the term *diversity factor*, which is the ratio of the sum of the maximum loads of the individual consumers supplied from any station during a given period, to the maximum load delivered from the station during the same period.

This gives a figure greater than unity, but many writers invert the ratio and obtain a figure for the diversity factor less than unity, which can be expressed as a percentage. The "consumers" may be either the actual consumers, or the various feeders radiating from a power or sub-station.

Suppose there are three consumers, or groups of loads, A, B, and C. These loads may be tabulated as follows :—

Consumer.	Amount installed (kW).	Nature of load.	Maximum demand (kW).
A	100	Lights only	70
B	100	Motors only	65
C	300	Lights and motors	215

The sum of the maximum demands of these three consumers is thus arrived at. But, as power for motors is in most cases demanded during the hours of daylight and power for lights during the hours of darkness, it is improbable that B will demand anything like 65**kW** while A wants 70**kW**. At the same time, when A is taking his full demand that of C will probably diminish. At this point, former experience will be of assistance in finding out what proportion of this 350**kW** should be installed in the generating plant. This will vary, both with the class of load and with the district. For example, in foggy places and in manufacturing districts lights are likely to be required much more than in country places, and it is possible that the motor load may be, at any rate in part, a night load. Each case must be considered on its merits, and it can only be stated that the diversity factor will probably be somewhere between 1·25 for a small group of similar consumers, and 5 for the whole of a large system with many types of load. In the example given, suppose that, for the district and class of load, it has been found that a diversity factor of 1·4 is approximately correct. To meet the combined demands of A, B, and C, $350 \div 1{\cdot}4 = 250$**kW**, would be sufficient.

3. **Load factor general.**—A third factor, which has an important bearing on the economical running of a station, has now to be considered. This is known as the *load factor*, and is the ratio of the average load to the maximum load during a prescribed period of time. It may be applied to the whole station, to a machine or group of machines, to a district, or to a single consumer ; it may also apply to any period of time, in some cases the running hours only being considered, and care should

be taken to specify definitely the period over which the average is taken. The ratio must necessarily be less than unity, but the aim of the central station engineer is to keep it as high as possible, for the following reasons :—

i. *The higher the load factor the less will be the running costs per unit.*—The effect of load on efficiency has already been discussed (Sec. **5**). It is, therefore, obvious that the higher the load factor the higher will be the machine efficiency, and, consequently, the smaller will be the coal consumption per unit. Not only will fuel and stores work out at a lower figure per unit for this reason, but the wages bill will also be more favourable. Whether the machines are working fully or lightly loaded, the personnel required to run them will be the same within reasonable limits ; consequently, the more units that are generated the less will be the wages costs to be apportioned to each unit.

ii. *Standing charges will be reduced.*—In military stations the interest on capital and the funds to meet the depreciation of plant are provided, in theory at least, by the State, and not by the particular authority controlling the power station. However, in working out the true cost of power supplied, these standing charges must not be neglected but taken into consideration equally with the running costs.

The rates at which electrical and other machinery is to be depreciated are given on AF. N 7534, reproduced in Appendix II. The capital value of plant and machinery will be shown in the books of the establishment using them.

Sums representing depreciation and interest on capital, at the current rate, must be added to the actual running expenses in estimating the costs of the electrical units generated. As in the case of running costs, the better the load factor the more units will there be over which to distribute these fixed charges.

It follows from this that, in cases where the load factor is high, it will pay to secure more economical plant by a higher first cost. If the load factor is low, the greater economy attained will not compensate for the higher standing charges.

4. Station load factor.—When the term **load factor** is used without qualification it invariably means the **Annual Station Load Factor,** and, expressed as usual as a percentage, it is given by the following formula :—

Station load factor =

$$\frac{\text{Total kWh generated during the year} \times 100}{\text{Maximum demand (kW)} \times 365 \times 24}$$

The following examples will serve to illustrate the principles involved :—

(*a*) A certain station in one year generated 200,000 units, and the maximnm load recorded on the station in the course of the year was **250kW.**

The station load factor for that year was then $\frac{200{,}000 \times 100}{250 \times 365 \times 24}$ or about 9 per cent., which is a poor figure and means expensive electrical energy.

In order to obtain a good yearly load factor, say some 30 per cent., the station would have to increase its sales to 660,000 units for the same maximum load, *i.e.*, **250kW.** This would imply finding fresh customers who would require energy during otherwise slack hours.

(*b*) A second station generated 700,000 units per annum at a yearly load factor of 17 per cent. Running costs worked out to 2·5d. per unit, and a sum of £4,500 per annum had to be charged, in addition, to meet interest and depreciation.

Each unit then had to be debited for fixed charges with $\frac{4{,}500 \times 240}{700{,}000} = 1{\cdot}54\text{d.}$

The total cost was then 4·04d. per unit. If 1,400,000 units had been generated in the year instead of half that number, or, in other words, if the load factor for the year had been improved to 34 per cent., the standing charges would have been only 0·77d. per unit. Running costs per unit would also have decreased.

5. **Running plant load factor.**—The matters so far considered are almost entirely outside the control of the power station engineer : only in the event of there being large secondary batteries can he improve his load factor by judiciously arranging his charging periods. The military engineer has an advantage over the civilian in this respect, as he is frequently in charge also of electrically driven sewage or water pumps, and is thus a consumer as well as a producer. By arranging his hours of pumping he can often obtain astonishingly high load factors.

But although the station load factor is largely fixed by outside considerations, careful management can ensure that such plant as is running is properly loaded, in other words, that the *running plant load factor* is high. As far as low fuel consumption goes, this is just as effective as a high overall station load factor.

The running plant load factor is defined as follows by the Diesel Engine Users' Association:—

Running plant load factor

$$= \frac{\text{Total } \mathbf{kWh} \text{ generated by Set I} \times 100}{\text{Rated full load } \mathbf{kW} \text{ of Set I} \times \text{hours run}} + \frac{\text{Total } \mathbf{kWh} \text{ generated by Set II} \times 100}{\text{Rated full load } \mathbf{kW} \text{ of Set II} \times \text{hours run}} + \&\text{c.}$$

6. **Station plant load factor.**—This is a third method of specifying the load factor which is sometimes used. It is defined by the D.E.U.A. as follows:—

Station plant load factor

$$= \frac{\text{Total } \mathbf{kWh} \text{ generated per annum} \times 100}{\text{Total capacity of plant } (\mathbf{kW}) \times 8760}$$

7. **Power factor.**—This factor needs consideration only in the case of an A.C. supply station.

The power factor in an A.C. circuit is expressed as the ratio of the true watts in the circuit (as measured by a wattmeter) to the apparent watts or the product of the voltage and current in the circuit (as measured by a voltmeter and an ammeter).

This is in practice almost always a little less than unity, and it is of the greatest importance to keep it as near that figure as possible. A low power factor implies, at a given voltage, a large current for a given power. This reduces the maximum output of alternators (*see* Sec. 7) and entails extra heating of conductors. The latter may necessitate heavier cables for the transmission of a given power, *i.e.*, increased capital expenditure.

This subject is dealt with in detail in Sec. **34**.

7. *Installation of machines.*

1. It is possible now to settle the total *amount of power to be installed* in the station, and the way in which this total is to be made up, *i.e.*, the *number of machines and the output of each.*

It is necessary in the first place to determine the maximum demands of the various groups of consumers, and then to settle the diversity factor for all these groups together. It will probably be necessary to draw upon the experience of others in order to arrive at suitable assumptions.

The usual method for ascertaining the foregoing, especially for small stations, is to consider the probable load on the station for each hour on any day in the year, the process being repeated for as many separate days as may be necessary. In temperate climates, at least two typical days must be considered, one in summer the other in winter.

These varying loads throughout the day are conveniently plotted as curves, with hours as the abscissæ, and loads, usually in kilowatts, as the ordinates. Examples of such **load curves** are given on Pl. **1.** From these curves can be obtained the probable peak or maximum load on the station, probable load factor, and the expected total number of units to be generated per annum.

In estimating the probable demand, the following figures relating to the consumption of electricity in the United Kingdom in the year 1925–1926 may be of use :—

Average lamps installed per battalion	1 per head.
Average watts per lamp	32
Average hours per lamp per annum	995
Consumption per lamp per annum	**30kWh.**

Thus an average battalion may be expected to use 30 × 750 or 22,500 units a year.

2. The aggregate power to be installed will be determined by the peak load, subject to the following further considerations :—

- i. A reasonable allowance of spare plant.
- ii. Overload capacity of engines and generators.
- iii. Power loss in distribution and station auxiliaries.

i. It is impossible to lay down any hard-and-fast rule as to **spare plant.** The general problem, *i.e.*, as to what percentage of the power installed is to be regarded as spare, depends for its solution upon—

(*a*) *The size of the station.*—In general, the larger the station the smaller will be the percentage of the total power installed regarded as spare.

(*b*) *The station load factor.*—Obviously the higher this is, the greater must be the percentage of spare plant installed. Since a high load factor implies that all the machines are constantly operating at a good load, not only will there be less time for overhauling the machines, but a breakdown of one may bring a dangerous overload on the remainder, unless a spare machine is available to take the load.

(*c*) *The nature of the load on the station.*—It is here that the military engineer has a very distinct advantage over the civil engineer. To the latter it is essential that each one of his customers must be able to obtain his full amount of electrical energy whenever he pleases.

The case of the military station is, however, different. Lights come on and go off by bugle-call; motors are run during certain hours only; and, in fact, the load is mapped out for every hour in the year.

It may even be possible, in the event of a serious breakdown at a military station, to issue orders forbidding the use of certain lights, &c., until such time as repairs can be carried out.

ii. The permissible **overload on a generator** depends upon the temperature rise in the armature and field coils, excessive heat causing injury to the insulation thereof. The possible overloads that may be safely incurred depend upon how the rating of the generators is fixed.

The British Standard Specification for the Electrical Performance of Industrial Electric Motors and Generators (B.S. Specification No. 168) details the capacity for sustained and momentary overloads of all commercial motors and generators. In this specification the normal continuous rating of the open type of generator is based upon a maximum temperature rise of 40° C. in the windings and cores, and 45° C. in the commutator or slip-rings, and the overloads permitted are as follows:—

Size of generator.	Overload in current at the full-rated volts.
7½**kW** (or **kVA**) per 1,000 r.p.m. and upwards	25 per cent. for 2 hours.
Below 7½**kW** or (**kVA**) per 1,000 r.p.m. and down to 3**kW** (or **kVA**) per 1,000 r.p.m.	25 per cent. for ½ hour.
Below 3 and down to 1**kW** (or **kVA**) per 1,000 r.p.m.	25 per cent. for 15 minutes.
All sizes	50 per cent. for 1 minute.

It does not, however, follow that these allowances hold for all generators, and it is advisable to study the specification of a machine before submitting it to an overload. It should also be remembered that the overload allowance may have to be reduced on account of the age of the machine or of climatic conditions.

A point which is often overlooked in this connection is that the engines must be capable of meeting the overload on the generators. Steam engines can be loaded beyond their rated output, and this is frequently done in practice at the expense, however, of the overall efficiency of the plant. I.C. engines, on the other hand, have practically no overload

[To face p. 32.

Plate I.

(See Section 7.)

EXAMPLES OF LOAD CURVES.

Fig. 1.

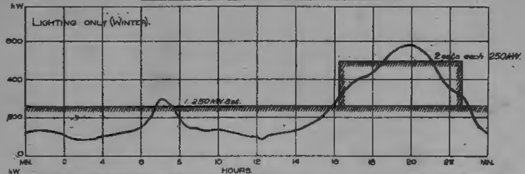


Fig. 2.

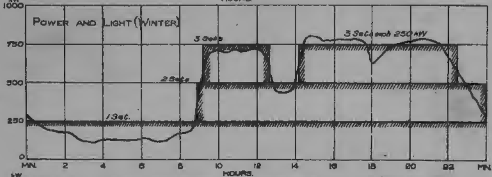
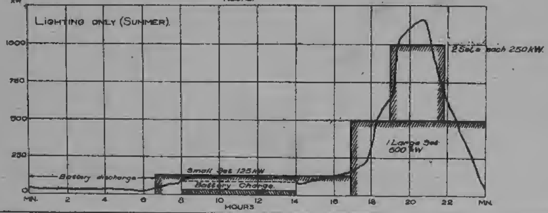


Fig. 3.



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Malby & Sons, Photo-Lith.

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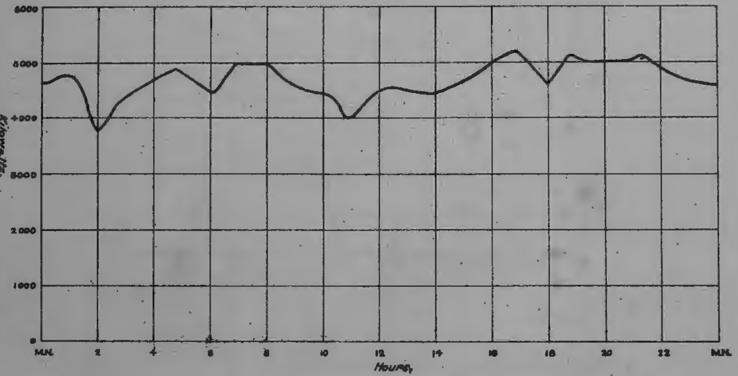
LOAD CURVE OF GRETNA MUNITION WORKS POWER STATION.

January 29th 1918.



Units generated.---116,900
Station Units.--------6,120
Average load---------4,870kW

Plate 8.
(See Section 5)

capacity, with the result that, if the generator is to be overloaded, an engine of greater rated capacity must be installed than would suffice to run the generator at its rated output.

iii. Suitable allowance must be made for the losses in distribution and for the power used by the station auxiliaries.

3. It is now necessary to determine how the plant to be installed is to be subdivided, *i.e.*, are there to be 20 machines each of 5 per cent. of the total power installed or only one which will do all the work from minimum to maximum loads? The answer will lie somewhere between the two, subject to the following considerations :—

i. There should always be some spare plant, as a single machine without a battery cannot be relied upon to give continuous service indefinitely. Generally speaking, at least 25 per cent. of the capacity installed should be spare, and it is desirable to allow for the largest unit being under repair at the time of maximum load.

ii. Units should be as large as possible. Not only are they cheaper per kilowatt at first cost, but their fuel consumption is lower.

iii. Generators should operate at or near full load for as long a time as possible. This consideration conflicts to a certain extent with (ii) since it is obvious that by sufficiently subdividing the plant it could be ensured that no generator would ever run except at full load. It must be remembered, however, that small sets are never so economical as large ones, and it may well happen that the fuel consumption per kilowatt of a small set at full load is no better than that of a larger set at half load.

iv. If possible, sets should be similar in make and in size. This facilitates repairs, renders superintendence and running much easier since there is only one size and type of machine to be dealt with, and very much reduces the stock of spare parts which must be kept.

4. It is possible now to examine in detail the load curve shown on Pl. 1, Fig. 1.

It will be seen that there is a morning peak of some 300**kW** and an evening peak of 600**kW**. The duration of both these maximum periods is short, and one 250**kW** set can readily deal with the daytime peak, the machine being loaded up to 300**kW**, or 20 per cent. overload, for less than an hour. This is, of course, only possible with steam sets. As the evening load comes on, at about 4.30 p.m. a second 250**kW** set is put in with the first, the two working in parallel until the load falls again to 300**kW** at about 11.0 p.m. It will be noticed that the second set is not put in until the first is slightly overloaded, and is taken off again before the load has dropped to the rated capacity of a single set. The evening peak is taken by the two machines together, each working at about 20 per cent. overload.

One set is idle for a considerable part of the 24 hours, during which time necessary adjustments and repairs can be made. There is obviously nothing to be gained in this case by having sets of different sizes.

On Pl. **1**, Figs. 2 and 3, are shown two more load curves and possible ways of dealing with them.

On Pl. **1**, Fig. 2, the period of very light load is short, and it will not be worth while to install a small set to deal with this. Three machines, each of 250**kW**, will deal with the load efficiently.

On Pl. **1**, Fig. 3, however, the case is different. The load factor is extremely bad, and there is a long period of very light load. The high generating and standing charges unavoidable with a load of this kind could be minimized by installing one small set of 125**kW** to deal with the light load, a battery to take the load by night, and two sets of 500**kW** each to take the peak. The small set would then be shut down for about 14 hours out of the 24, and the two big sets for about 16 hours.

If these curves (Pl. **1**) be the estimated load curves of *new* stations, it would probably be advisable to install machines of slightly greater capacity than those indicated, in order to allow for future additions to the systems.

Pl. **2** shows a load curve which was obtained at *Gretna Munition Works Power Station ;* this is an ideal example of the possibility of arranging power to be taken at definite times.

8. *Parallel running of generators.*

1. In all stations it will be necessary to run two or more generators in parallel to supply the load, and in this connection several points arise which are not usually considered.

Pls. **34**, **35**, and **37** show sufficient switchgear for all normal running, and reference should be made to these plates while reading this section.

2. D.C. machines in order to share a load satisfactorily in parallel must have drooping, or at any rate level, load characteristics, and they must therefore be either shunt wound or under or level compounded—in the latter case an equalizing bar as shown on Pl. **34** is necessary. Shunt machines should be specified where possible on account of their simplicity, but they have a poor voltage regulation, as shown in the table below, and are unsuitable if the load is one with big fluctuations. The standard service 5**kW**

110-volt set has a compound generator fitted with a switch to short-circuit the series winding so that the machine may be used for battery charging.

It is desirable that the regulation of all machines intended for parallel running should be about the same, and the following table gives the values that may be expected from present-day commercial machines :—

	Generator.	Combined set.
	per cent.	per cent.
5kW D.C. Shunt wound generator driven by high-speed petrol engine ..	15–25	25–30
75kW D.C. Shunt wound generator driven by heavy oil engine	9–12	12–15
75kW D.C. Level compound generator driven by heavy oil engine	—	4–6
75kW Alternator generator driven by heavy oil engine—		
(*a*) Unity P.F.	10–15	15–20
(*b*) 0·8 P.F.	25–30	35–40
1,000kW 3-phase turbo-alternator unity P.F.	30	40

It is of importance to note that the regulation of interest in this matter is that of the generating set as a whole. However well designed the governing gear of the prime mover may be, some speed variation must take place when the load alters in order to actuate the governor, and this variation must be allowed for in carrying out tests if the generator and the prime mover have to be tested separately.

3. The desideratum when bringing a new machine on to the bus-bars is the least possible voltage disturbance at the moment of closing the switch. The following order of operations is recommended :—

D.C. generators :

1. See that field rheostat is *all in.*
2. Bring machine up to rated speed.
3. Close equalizing switch.
4. Plug in paralleling voltmeter.
5. Close field switch.
6. Alter field rheostat until machine voltmeter reads a few volts higher than the bus-bar voltmeter.
7. Close main switch or circuit-breaker.

To make the incoming machine take over part of the load, gradually increase its field strength, decreasing at the same time the fields of the other machines.

If the sets are well designed any moderate change in the load will be shared equally by all the sets.

Alternators (*see* Sec. **15** (10)) :

1. See that field rheostats are *all in.*
2. Bring machine up to its approximate speed.
3. Close field switch. (Field connections are not shown in Pls. **35** and **37**.)
4. Regulate main field and exciter field rheostats until the machine voltmeter reads one or two volts higher than the bus-bar instrument.
5. Insert synchronizing plug.
6. Signal to the engine-driver to vary the speed of the set in accordance with the synchroscope indications.
7. Close the main switch when the synchroscope needle is motionless in the position indicating synchronism, or when it is close to and moving *very slowly up* to this position.

Varying the generator fields will in this case have little effect on the sharing of the load, but will only vary the amount of wattless current, and, in consequence, the power factor of each machine.

To make an incoming machine take up load the fuel valve of the prime mover must be opened by hand or servo-motor and those of the other sets closed. If the new machine is supplying a large proportion of the total load of the station, its field rheostats must be carefully watched to ensure that the frequency remains steady, but if it is under 20 per cent. or so of the whole output the other plant will keep it in synchronism.

As shown by the table in para. 2, the regulation of alternators is much worse than that of D.C. generators, especially at low power factors, and it is essential to have an attendant constantly on the switchboard if the load is one, such as motor generators supplying searchlights, liable to sudden variations. In all big power stations, special regulators, of which the Tirrill and the Brown-Boveri are well known types, are installed to keep the bus-bar voltage steady.

4. **Field regulation.**—Mistakes are often made by switchboard attendants owing to a misconception of the proper use of shunt field rheostats. Engine-drivers of oil engines often run for some time about 10 per cent. or so under the proper rated speed when first starting up, and with the governor in consequence not operating. To get the correct voltage under these conditions the field rheostats will have to be almost entirely cut out. If the load now increases the voltage will fall and the attendant will try to bring it up by means of the rheostat and be unable to. The correct procedure is to weaken the field momentarily. This will reduce the voltage and the load on the engine, which will then be

able to pick up to its proper speed, at which there should be no difficulty in maintaining the voltage.

With alternators it is generally found desirable to have rheostats in both the main field circuit and the exciter field circuit, the latter giving coarse adjustment, and the former fine regulation. Provision of the main field rheostat enables the exciter load characteristic to be varied, and this leads to greater stability in working. When automatic regulators are used, however, the main field rheostat is generally dispensed with.

9. *Power station routine.*

1. **Reliability** and **Economy** are the two main desiderata in power station running ; and of these reliability is by far the most important to the military engineer.

2. **Reliability.**—No golden rules can be laid down for securing freedom from interruption of supply. A systematic routine of overhaul and inspection should be adhered to and is the only precaution that can be taken. It should be borne in mind that the failure of an auxiliary, a boiler feed pump or water circulating pump, for example, is more likely to occur than a major accident and yet will just as effectively cause a shut down.

3. Regulations for R.E. Services, Part II, deal with inspections and overhauls and give a specimen chart for these. The following matters may be mentioned as needing periodical attention :—

Grinding in the valves of oil engines.
Cleaning air, water and oil filters.
Cleaning out oil switch and transformer tanks.
Inspection and cleaning of switch contacts.
Boiler, economizer, and condenser cleaning.
Insulation testing of all electrical plant, switchgear and cables.
Blowing out of electrical machinery.
Testing of relays, trips, and all protective devices.
Testing of all emergency apparatus, *e.g.* stand-by lighting and batteries.

Steam plant needs careful treatment and should be warmed up for a period before being put on load. With oil engines indicator cards on all cylinders should be taken once a month and filed : differences will thus be immediately noticeable if the cards are taken under exactly similar conditions. Exhaust pyrometers are useful, as equality of exhaust temperatures is a good indication that the cylinders are sharing the load properly. If good results are to be obtained oil engines should not be run at more than 80 per cent. of their rated output for long periods on end.

4. **Economy.**—The maximum possible thermal efficiency of a station is settled by its design, but the difference between this and the efficiency obtained over a long period may be diminished by assiduous application to detail and the careful keeping of accounts by the power-station staff. Thermal efficiency in itself is of no importance whatever except as a means to the end of a low overall cost of electricity per unit ; it will frequently be found to pay to sacrifice thermal efficiency in order to reduce maintenance or standing charges. However, thermal efficiency must not be neglected.

In most cases over 90 per cent. of the heat losses occur in the prime mover and its auxiliaries, and, electrically, little can be done beyond keeping the plant clean and in good repair.

Small steam-power stations show great economy if the exhaust steam can be used for heating buildings or for other purposes. (Fort George, in Scotland, is heated in this way.)

Steam engine efficiency can be kept high by special attention to maintaining the vacuum, and to all joints. Running plant load factor (*see* Sec. **6**) is of more importance in this connection than station load factor, and can be safeguarded by standing orders to attendants directing which plant should be run for all likely load combinations.

As the main losses are in the boilerhouse, so can most be done here to secure economy. CO_2 indicators can be put in places easily visible to stokers, and recording instruments used, too, if the station is large enough to justify it. Boiler load factors can also be studied with advantage.

It will never pay to run a boiler furnace with defective brickwork. The defects should be made good and the cause of them removed immediately they are noticed.

Information on the running and maintenance of boilers, steam plant and oil engines is given in the Military Textbook of Mechanical Engineering.

The main points affecting economy which drivers of oil engines must watch are the cooling water temperature, clearness of exhaust, and, with air blast engines, the blast pressure. The consumption of lubricating oil can be considerably reduced if some form of filter is installed either in the oil circulating system or separately.

5. **Accounts.**—Operating accounts of W.D. stations are rendered quarterly on Army Form N 7534, which is reproduced in Appendix II, and is self-explanatory. The proportion of wages to be allotted to generation and distribution is laid down for each station, and the remainder of the standing charges, including the rate of depreciation to be charged, are given in Army Council Instructions from time to time.

10. *Details of existing military stations.*

1. Appended are brief descriptions of three military generating stations at Aldershot, Tidworth, and Pembroke, Malta ; employing respectively steam plant, air blast and solid injection heavy oil engines, and Hornsby old-type horizontal oil engines ; they are taken as examples of the class of power-station work that may have to be undertaken by military engineers.

2. **Aldershot.**—The first plant was installed in 1902, and comprised six 5,000-lb. Babcock & Wilcox boilers supplying three 250**kW**, 450-volt D.C. Parsons Turbo-generators and a 100**kW** steam balancer set ; a 1,000-amp.-hour storage battery dealt with the day load.

Three-wire distribution was employed, the declared voltages being 400/200 volts. Paper-insulated lead-covered cables laid solid in bitumen were used.

Expansion in load, and in plant to meet the load, has taken place frequently since. In 1909 mechanical stokers were provided for the boilers, and it was decided to supply Ewshott, Blackdown, and the Balloon Establishment at Farnborough. H.V. transmission was obviously indicated, and a 3,300-volt 3-phase A.C. system was decided upon. More boilers, a 313**kVA** turbo-alternator, and synchronous motor-generators were installed. The lines to Blackdown and Ewshott are aluminium, strung on wooden poles, and distribution is 3-phase 4-wire 346/200 volts.

Up to 1919, boilers, generators, &c., were added piecemeal as found necessary. In that year the probable future scope of the station was considered as a whole. The original Parsons sets were worn out and were scrapped ; various further districts were included in the area of supply, and the voltage of the Blackdown feeder raised to 6,600 volts, that of the Ewshott and Farnborough lines being similarly raised in 1925.

In 1922 a bulk supply was commenced to the town of Aldershot, and in 1926 Farnham also took a small supply. The small oil engine stations at Bordon and Longmoor were closed down in that year and these camps supplied by means of a 6,600-volt cable laid direct in the ground as far as Bordon, the extension to Longmoor being by means of an overhead line. To cope with these extra demands a 2,000**kW** Brush Ljungstrom turbo-alternator was installed, and the boiler-house arrangements modernized. Two of the 5,000-lb. boilers were adapted for oil firing for emergency use.

The installed plant now consists of :—

One 25,000-lb. and two 15,000-lb.-per-hour boilers with chain grate stokers and superheaters to give a superheat of 200° F.

Other smaller boilers, making up the total steaming capacity to 85,000 lb. per hour.

6,600-volt turbo-alternators of a total capacity of **5,625kVA.**

Two **940kVA**, 6,600/440-volt La Cour Motor Converters.

Appendix I gives a cost of production account for the year ending 31st March, 1929; Pl. 3 gives the load curve on 2nd December, 1927, and Pl. 4 the curve for a day two years later. Note the expansion that is inevitable with electric power supply.

3. Tidworth.—The power station at Tidworth, which commenced operation in 1914, was originally designed to supply D.C. to Tidworth at 240/120-volts (3-wire) and A.C. to Bulford at 200/120-volts, 50-cycles (3-phase, 4-wire). The distance from Tidworth to Bulford being 4 miles, a 3,000-volt, 3-phase, H.V. transmission line was erected with 0·1 sq. in. aluminium conductors. The approximate D.C. load at Tidworth was 300kW and the A.C. load at Bulford **150kW**, and in 1915 the maximum winter load was 450kW and the total units supplied 600,000.

To meet the requirements of this particular load three 375 B.H.P. Mirrlees, Bickerton and Day Diesel (Air-Blast) Oil Engines were installed, each engine driving a **175kW** D.C. generator and a **75kW** alternator on one shaft.

A 1,500 ampère-hour battery was installed and a combined Booster-Balancer set. A **25kW**, 3-phase, 3,000-volt alternator was also coupled to this set by an electromagnetic coupling—that is, there were five machines in line on the same bedplate. The *night* load was taken by the battery, the balancers being used to drive the alternator to maintain the Bulford supply.

During the 1914–18 War it became necessary to erect power stations at Perham Down (126kW), Ratfyn (830kW), Porton (130kW), and Netheravon (125kW). The first two were 3,000-volt steam stations; that at Porton first a petrol and subsequently a combined steam and I.C. engine-driven D.C. station; and that at Netheravon was partly driven by a water turbine. A H.V. feeder was run from the Ratfyn power station to Bulford and connected there to the Tidworth—Bulford feeder, thus enabling Ratfyn to take the night load of the Tidworth power station. The necessary conversion was done by a **150kW** synchronous motor generator at Tidworth.

After the war many temporary camps were demolished, but those at Perham, Porton, and Larkhill were retained, to be replaced gradually by permanent buildings. The transmission system was extended to include all these places, the small power stations at Perham, Porton, and Netheravon

PLATE. 3.

WINTER LOAD CURVE of ALDERSHOT MILITARY POWER STATION.

DECEMBER 2ND. 1927.

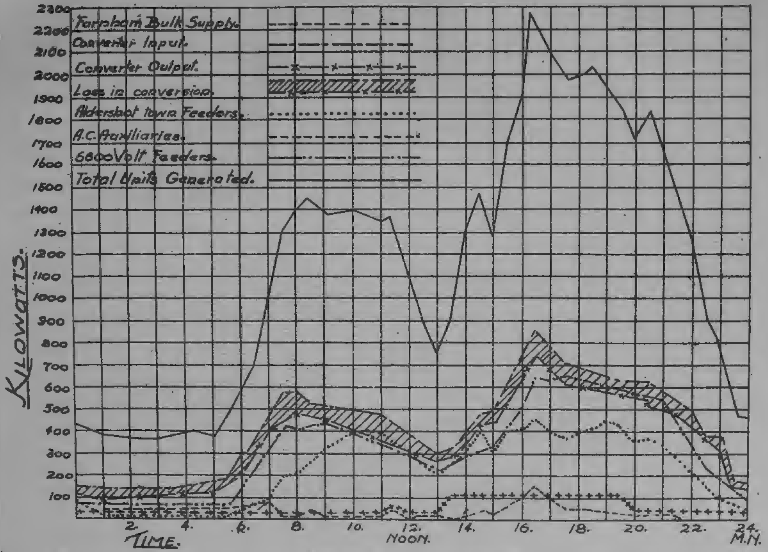


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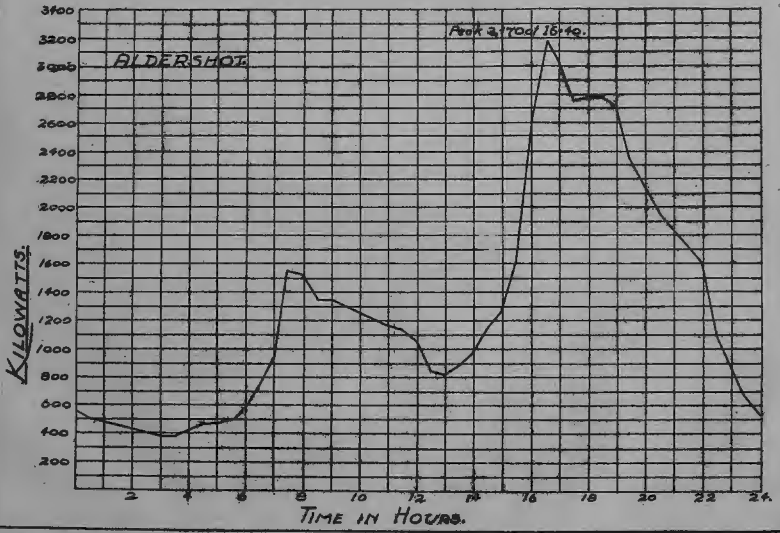
PLATE. 4.

LOAD CURVE FOR TUESDAY DECEMBER 10th: 1929.
[TOTAL LOAD ON PRIME MOVERS].



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WINTER LOAD CURVE OF TIDWORTH MILITARY POWER STATION

PLATE 5

Date: Tuesday, 13th Jan. 1931.

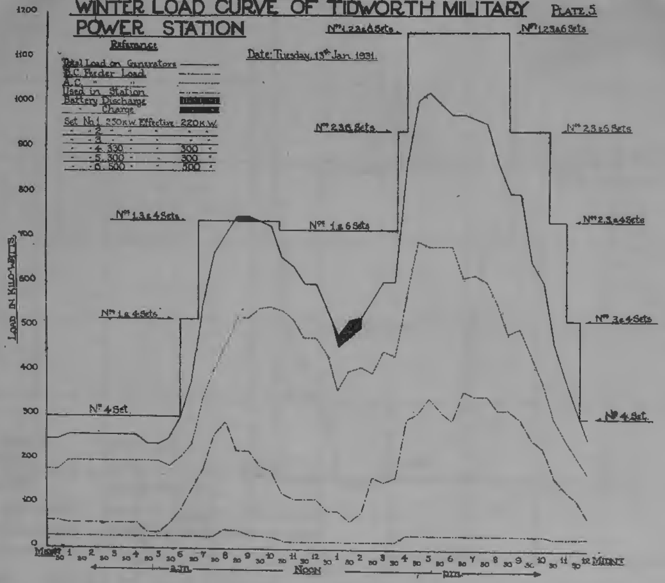

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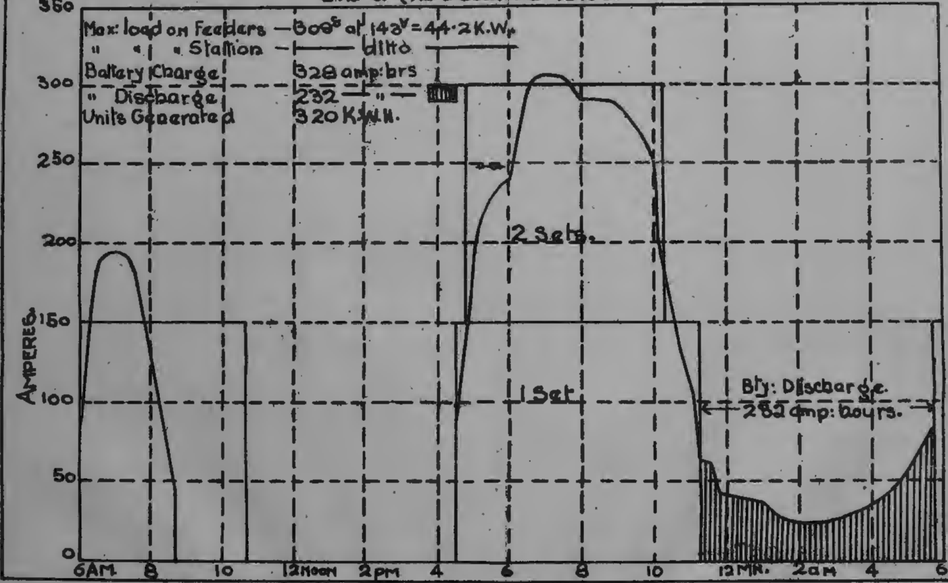
PLATE. 6.

LOAD CURVE. PEMBROKE POWER STATION. MALTA.

6th & 7th December 1928.



were abolished, the Garrett sets at Ratfyn were replaced by a Fullagar Diesel, and a fourth set was installed at Tidworth.

The centre of the load distribution had by now shifted to Bulford. Ratfyn generated at 6,600-volts, and step-up transformers raised the Tidworth—Bulford line to 6,600-volts, the primary voltage at Tidworth being altered from 3,000-volts to 3,300-volts.

The steam-driven pumping stations supplying Tidworth, Bulford, and Larkhill were converted to electrical drive, and bulk supply was given to the R.A.F. at Upavon, Netheravon, and Boscombe Down.

To cope with increased demand a fifth set was installed at Tidworth in 1930, and on account of Tidworth's growth the outlying portion of its D.C. distribution has been changed to A.C. As opportunity offers, standard voltage is being installed throughout the system, and eventually D.C. will be retained at Porton only, where it is required in the research laboratories.

The following generating plant is now installed :—

Tidworth Power Station :

Three 250kW Mirrlees, Bickerton and Day Air-Blast Engines (1914).

One 370kW English Electric Air-Blast Engine (1921).

One 300kW Davey Paxman Spring Injection Engine (1930).

Ratfyn Power Station :

One 500kW English Electric Fullagar Air-Blast Engine (1924).

The operation account for 1929–1930 will be found in Appendix II, and on Pl. **5** is given a typical winter load curve.

4. **Pembroke, Malta.**—In 1912 it was decided to install electric lighting in St. George's and St. Andrew's Barracks at Pembroke.

For simplicity, the Service pattern Defence Electric Light type of plant was adhered to as much as possible.

The station comprises three 36-H.P. Hornsby Ackroyd engines, each driving a 22kW D.C. generator.

The distribution is 2-wire 130V. A 540Ah battery takes the day load and is charged by a booster set.

The curve on Pl. **6** was taken in Pembroke in December, 1928, and shows that the generators are kept well up to their rating during running hours due to the battery charge.

Some details of the cost of generation for 1926 are given in Appendix III ; costs have not altered appreciably since then.

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Power Station Operation, Vol. I. The "Electrical Times." 3*s*. 6*d*.

Electrical Engineering Practice, Vol. I. J. W. Meares and R. E. Neale. 25*s*.

British Standard Specifications. 2*s*. each :—

132. Steam Turbines for Electrical Plant.
211–213. Heavy Oil Engines for Electrical Purposes.
225. Electrical Performance of Alternators of the Steam Turbine Driven Type.
226. Electrical Performance of Large Electric Generators and Motors.
269. Methods of Declaring Efficiency of Electrical Machinery.

D.W. Standard Specifications for E. & M. Services :—

6. Steam Boilers.
8. Heavy Oil Engine Driven Generating Sets.
11. Power Station Auxiliary Equipment.

CHAPTER II.

SWITCHGEAR AND INSTRUMENTS.

11. *Air-break switches.*

1. **Air-break switches for voltages up to 660** (B.S.S. 109).

It is necessary to distinguish between—

- i. *A switch*—which is suitable for breaking a circuit carrying a load current, and
- ii. *An isolating switch*—(sometimes called a disconnecting link) which is suitable for disconnecting a circuit only when carrying no appreciable load current.

Modern switches and isolating switches are invariably of the " knife pattern." The current densities employed are about 1,000 amperes per square inch for the blades and 50 amperes per square inch for the contacts. The contacts must be well fitted to prevent undue heating and the contact resistance should not be greater than about one ten-thousandth of an ohm per square inch of contact area. A little vaseline on the contacts helps to make a good contact.

2. **The rated carrying capacity** of a switch is the largest current it will carry with a temperature rise not exceeding 20° C. for ratings below 100 amperes and 30° C. for larger currents.

3. **The breaking capacity** of a switch when tested at a voltage 50 per cent. greater than the rated value on non-inductive load should be at least 50 per cent. in excess of its carrying capacity. Good modern designs up to 200-ampere rating will effectively break seven to ten times the rated current at rated voltage.

For currents above 400-amperes rated carrying capacity, however, switches should not be used for breaking full load current, except in emergencies. Above about 800-amperes capacity it is usual to employ two or more blades in parallel to ensure better bedding of the contacts and improve the ventilation (*see* Pl. 7, Figs. 1 and 2).

It is now considered unnecessary to specify that the hinges of open-type switches should not carry current, since in modern designs the contact drop at the hinges is usually lower than at the knife contacts.

Except in cases where the inductance of the circuit controlled is high (*e.g.*, the shunt field coils of machines) it is desirable that the break should be as quick as possible as the repeated action of a prolonged arc would soon destroy the contacts. In open-type switches a "follower" blade is frequently attached to the main blade in order to facilitate a quick break. The follower is actuated by the opening of the main blade which extends a spring until the friction of the contacts on the follower is overcome, and quick final opening of the circuit is thus ensured. In cases where the switch is not intended to open the circuit on load the follower blade is unnecessary.

Although single-pole switches may sometimes be necessary, it is preferable in most cases to use two-, three- or four-pole switches so as to ensure that the whole circuit is disconnected by a single operation.

4. **Field breaking switches** for disconnecting shunt field windings and discharging the energy of the magnetic field into a non-inductive resistance, may be of similar design to an ordinary knife-switch with an extra contact to make circuit with the discharge resistance before the follower blade breaks the supply connection. D.P. field switches should be used except for the smallest machines. Pl. 7, Fig. 3, shows a D.P. field breaking switch, in which the follower blades are on the point of leaving the contacts. (Distance between centres of hinge and clip contact is 4½ in.)

5. **Ironclad switches.**—In power stations and sub-stations, open type switches are used on voltages up to 660, but it may be taken that for general purposes all switches should be ironclad (B.S.S. 124) on voltages above 250 D.C. and 125 A.C.

Pl. 8 shows a 3-pole interlocked ironclad switch-fuse for 60 amperes, 500 volts. To keep the overall dimensions of ironclad switches within reasonable limits and maintain adequate clearances from the earthed metal case, the ordinary knife-switch design is seldom adhered to. In the design illustrated a double break is arranged for and the moving parts, which are hinged at the centre, form jaws which make on to stationary blocks. Using a double break on each pole reduces the amount of travel for a given clearance between contacts in the "off" position. A spring connection with the operating handle ensures a quick break and enables a follower blade to be dispensed with. It is impossible to remove the cover until the switch is in the "off" position, and if the incoming connections are brought into the bottom of the switch (as they should be) the switch blades and fuses are dead when the cover is opened. Note the isolating barriers between the poles to prevent arcs striking across and the insulating lining to the case to prevent "earthing" arcs.

6. **Isolating switches on H.V. circuits.**—On H.V. circuits, which are generally A.C., air break switches are never

PLATE 7.

HEAVY CURRENT SWITCHES.

Fig. 1.—6,000A Switch. With 4-in. blades in open position to show contact clip.

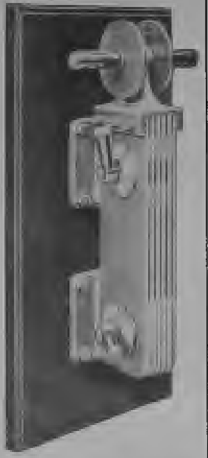


Fig. 2.—8,000A Switch. With 6-in. blades.

[*Permission of The British Thomson-Houston Co., Ltd.*

FIELD BREAKING SWITCH. (100 Amps.)

Fig. 3.

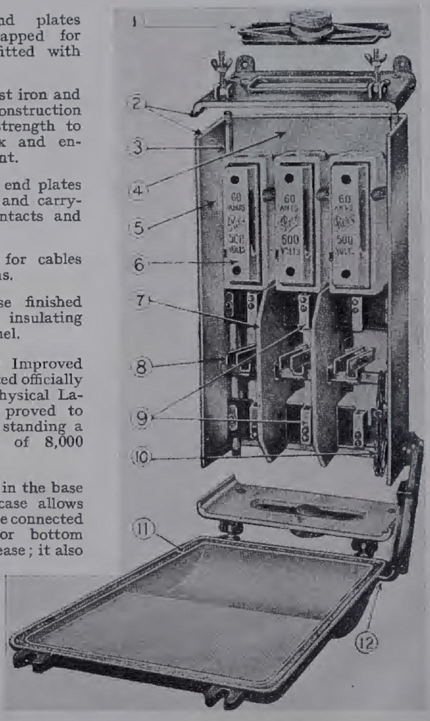
[*To face p.* 44.

3-POLE, INTERLOCKED, IRONCLAD SWITCH FUSE.

(500 Volts, 60 Amps.)

Overall dimensions { Height $16\frac{1}{4}$", width $9\frac{5}{8}$", depth $8\frac{7}{8}$", including projection of handle $2\frac{3}{8}$".

1. Detachable end plates drilled and tapped for conduit and fitted with wood bushes.
2. Substantial cast iron and steel trough construction giving great strength to the whole box and ensuring alignment.
3. Bars clamping end plates to steel body and carrying switch contacts and mechanism.
4. Ample space for cables and connections.
5. Inside of case finished with special insulating porcelain enamel.
6. "Revo" New Improved Fuse Units tested officially by National Physical Laboratory and proved to be capable of standing a short circuit of 8,000 amps.
7. A wiring duct in the base of the steel case allows the cables to be connected to the top or bottom contacts with ease; it also allows a neutral wire to run through.
8. Twin grip contacts of H.C. copper under spring pressure.



[*Permission of Revo Electric Co., Ltd.*

9. Rapid and smooth double break on each pole, which ensures safety when breaking heavy excess currents.
10. Positive quick make and break movement.
11. Case when assembled and painted is fitted with gasket in lid to render it watertight.
12. Cover and handle are positively interlocked.

[To follow plate 8.

Plate 9.

ISOLATING SWITCHES.

6,000 Volts. (See Section. II.)

Fig. 1. Operating Rod.

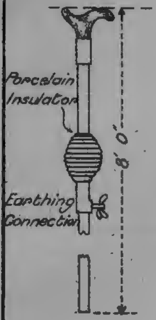
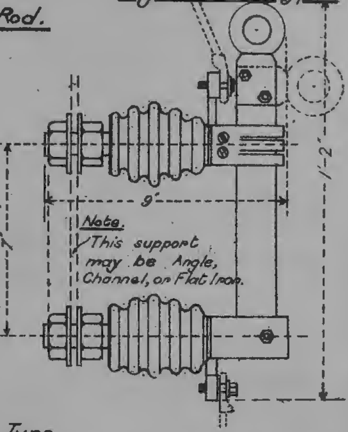
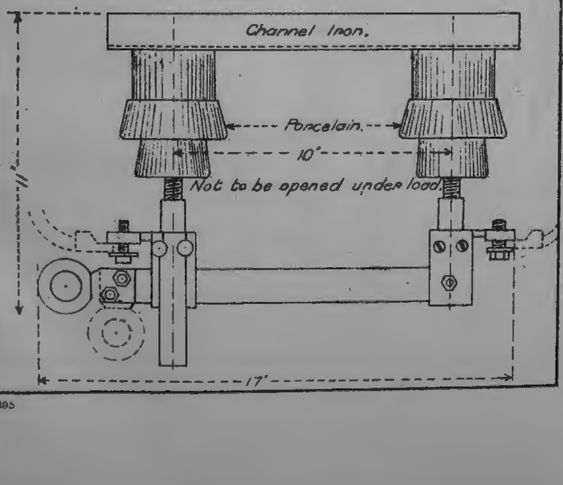


Fig. 2. Indoor Type.



Note. This support may be Angle, Channel, or Flat Iron.

Fig. 3. Outdoor Type.



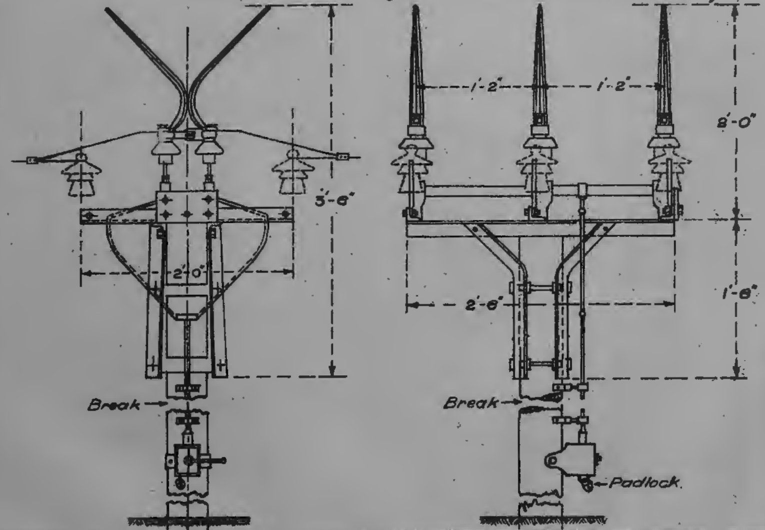
Not to be opened under load.

P3895

Plate 10

EMERGENCY SWITCHES.

Outdoor Air-Break Type. 6,000 Volts. (See Section II.)



P 3886

used except as isolating switches operated by an insulated rod (Pl. 9, Fig. 1), or in the case of the Truck-type Equipment by pulling out the truck, to render circuit breakers, fuses, &c., safe for handling during overhaul. The contacts are mounted on porcelain insulators suitable for the working voltage. Pl. 9, Fig. 2, shows an isolating switch for interior use, and Fig. 3 one with double-shed insulators for exterior use.

It must again be emphasized that these isolating switches are not intended to break circuit under appreciable load, and if they are put to such use dangerous surges may be provoked in the system and violent arcing and burning of the contacts will ensue. They may, however, be used to disconnect small transformers with their secondaries on open circuit, *e.g.*, the isolating switches illustrated in Pl. 9 have safe current-carrying capacities of 100 amperes, but their breaking capacities cannot be taken as greater than 5–10 amperes.

7. Pole-line emergency switches (Pl. 10).—This type of switch with horn break is often used for isolating sections of an overhead line system during testing and repairs. It is controlled from the foot of the pole. The arcs which occur at break tend to travel up the horns, partly by electromagnetic action and partly by convection, and become attenuated and break in the upper part of the horns when their intensity has become considerably reduced by elongation, and in this way damage to the main contacts is prevented. A strong wind will, however, modify this action. These switches must be allowed large clearances and should be above the conductors to prevent the possibility of arcs developing into shorts between phases. They should not be opened on load except in emergencies.

12. *Fuses* (*Fusible cut-outs*) (*B.S.S.* 88).

1. Fuses on L.V. and M.V. circuits.—For small circuits a simple fuse is the cheapest protective device. In all modern designs the fuse wire is carried inside a detachable holder of insulating material (porcelain or bakelite) provided with substantial brass contacts at the ends which fit into brass clips in the base. The arrangement ensures that fused metal cannot scatter and the insulated holder serves as a handle for removing the fuse.

2. Normal carrying current.—A fuse is rated on its normal carrying current, which is the maximum current it will carry continuously with a rise in temperature not exceeding that of the surrounding air by more than 30° C.

3. Fusing current.—When the time taken for the fuse to blow is one minute (two minutes in the case of lead-tin alloy) the fusing current should be double the capacity of the smallest cable which the fuse controls, provided that no fuse smaller than one rated to blow at 7 amperes need be inserted in any final sub-circuit (*vide* I.E.E. Regn. 68).

In certain cases, particularly in lighting circuits in which an abnormal current is invariably due to a short circuit or earth fault (if we exclude unauthorized additions), the fusing current might well be less than that specified above, say 50 per cent. only above the normal maximum current. In the case of motors subjected to several times excess torque for short periods it is unwise to fuse too closely (*see* Sec. **89**).

It is to be noted, however, that the permissible ratio of fusing current to carrying current depends very largely on the characteristics of the particular metal used for the fuse wire and also on the size, shape and construction of the fuse holder. (*See* Sec. **68** (3).)

4. **Rupturing capacity. (Maximum short-circuit current).**—The ratio of fusing current to carrying current is a measure of the protection afforded to apparatus and circuits, but in the case of a short circuit which might permit the passage momentarily of some thousands of amperes, a badly designed fuse may destroy itself in clearing or attempting to clear a fault. Hence the necessity for specifying a rupturing capacity.

The I.E.E. Regn. 68 (B) and B.S.S. No. 88 specify the following values for low-voltage " ordinary duty " cut-outs.

Carrying capacity.	*Rupturing capacity.*
10 Amperes.	1,000 Amperes.
30 ,,	2,000 ,,
60 ,,	4,000 ,,
100 ,,	6,500 ,,

For medium voltages (250–650 volts) no values are specified, but it may be assumed that the same values apply up to 650 volts.

The term " ordinary duty " is applied to a cut-out or fuse carrier when the maximum short-circuit current in the circuit cannot exceed the values given above. It is sometimes advisable to put in fuses of larger rated carrying capacity than necessary so as to provide a higher rupturing capacity. The maximum possible short-circuit current at any position in the system may be estimated approximately as follows :—

Suppose voltage at supply terminals = 400 at no load and 396 with a load of 30 amperes. Then the maximum possible short-circuit current $= 30 \times \frac{400}{4} = 3{,}000$ amperes. For the conditions assumed, a 60-ampere fuse holder should

"REVO" PATENT FUSE ELEMENTS.

(To Home Office Requirements—500 Volts.)

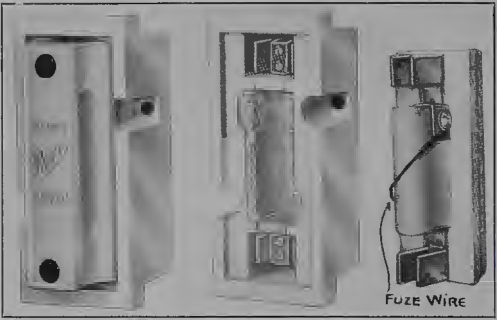


Fig. 1.

"REVO" PATENT IRONCLAD DISTRIBUTION FUSE BOARD.

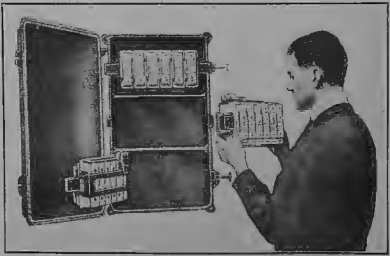


Fig. 2.

Permission of Revo Electric Co., Ltd.

be installed although the normal maximum working current may be less than 30 amperes. The working current will of course, still determine the size of fuse wire.

5. **Modern design of fuse holder.**—Enlarged views of a 30-ampere fuse holder of the same type as the 60-ampere fuses shown in Pl. **8** are given in Pl. **11**, Fig. 1. The fuse base is fitted with an arc chamber lined with an asbestos pad which absorbs any gas that may be formed when the wire fuses and so materially assists in quenching the arc and thus enabling severe short circuits to be dealt with safely. The whole length of the fuse wire contacts are so arranged on the handle that they are completely buried in the arc chamber, thus preventing the risk of arcing to the metal case. The main contacts are isolated from the arc chamber, and the base and fixing screws are arranged in such a manner as to be totally shielded and protected.

The overall dimensions of this design of fuse holder are :—

10/15-ampere		$1\frac{15}{16}'' \times 1\frac{1}{2}'' \times 3\frac{1}{2}''$
30	,,	$2\frac{7}{16}'' \times 1\frac{5}{8}'' \times 4\frac{3}{4}''$
60	,,	$2\frac{5}{8}'' \times 2'' \times 6''$
100/120	,,	$3\frac{9}{16}'' \times 2\frac{1}{2}'' \times 7\frac{1}{2}''$

6. **Ironclad distribution board.**—Fig. 2, Pl. **11,** shows a 3-pole, 6-way, 500-volts, 15-amps. distribution board with fuse holders of the same type. The overall dimensions of this board are: Height 23⅛ inches, Width 14¼ inches, and Depth 6¼ inches. The design complies with the regulations of the Home Office and of the I.E.E. All live parts are shrouded by insulating material and the person handling it is completely protected from shock and burns, even when the fuse carrier is replaced on a short circuit, and consequently the fuse blows while still in the hand. It is, of course, always desirable to install switches on the " live " side of fuses, but in commercial work they are frequently omitted on account of the expense. The type of fuse holder here described may be used on sub-circuits up to 500 volts without a switch.

7. **Fuse wire characteristics.**—i. *Time lag. Inverse time element.*—Since a definite quantity of heat is required to raise the temperature of a wire to fusing point, it follows that the time taken for a fuse to blow will be inversely proportional to the rate of heat generation and, therefore, to the square of the current density. This is a very valuable property to have in a device for the protection of apparatus and circuits against overloads which only cause dangerous heating if maintained.

Pl. **12**, Fig. 1, shows approximate current-time curves for silver, copper, and tin wires.

ii. *Fuse wires on L.V. and M.V. circuits.*—Copper, tin and tin-lead alloys are the metals most commonly used for L.V. and M.V. fuses. Tables of approximate fusing currents for copper and tin-lead alloy (75 per cent. lead, 25 per cent. tin), abstracted by permission from the I.E.E. Regulations, are given in Appendices VIII and IX. Particular attention is directed to the explanatory notes at the foot of Appendix IX.

The fusing currents of pure tin wire may be taken as 50–60 per cent. greater than for the 75/25 lead-tin alloy.

The cost of copper fuses is only a fraction of the cost of tin, as the weight per fuse and the cost per pound of the former are both much less than those of the latter. The cost of pure tin per pound is naturally greater than that of tin-lead alloy, but it is no more expensive per fuse, since the specific gravity of the alloy is greater, its specific resistance is higher and it has a lower melting-point.

Copper wire, if it is to keep cool and have a reasonably small power loss, must be of such a size that the wire will not fuse with a load of two or three times the normal maximum ; if run too hot it will oxidize and eventually open circuit with a current which may be less than the normal full load of the circuit. Moreover, in the latter circumstances, the working temperature of the fuse holder may exceed 30° C., the upper limit specified in the Regulations.

The use of tin or tin-lead alloy overcomes these disadvantages, although it introduces another in the large amount of metal which is volatilized when the fuse blows. This tends to make the rupturing arc more persistent, but it need cause no anxiety with modern designs of fuse holder.

Generally speaking, copper is better for large currents and for lighting circuits, but for ordinary house wiring, tin or tin-lead alloy should be used as the smaller copper wires are rather fragile and are liable to get into the threads of the clamping studs. Owing to its greater heat capacity, which gives it a greater time lag, tin fuse wire can be rated much closer than copper, and this is an advantage on power circuits where large overloads of short duration are frequent.

In cases where a very close rating is desired, Hope's " Bi-Metal " fuse wire may be found useful, combining as it does the advantages of copper with those of the tin-lead alloy. It consists of a tin-lead alloy with a copper core, and it will carry 90 per cent. of its fusing current indefinitely without deterioration. On overloads up to five times the normal working current, the alloy is melted and runs off before the circuit is finally ruptured by the copper, and very little metal is scattered.

8. Fuses on H.V. circuits.—The main disadvantage of fuses in H.V. work is that one leg only of a circuit may be

PLATE 12.

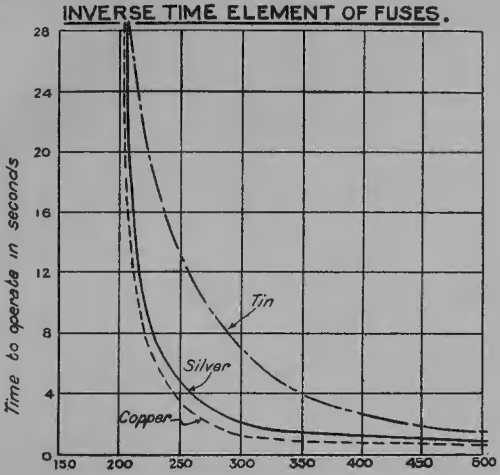


Fig. 1.—Percentage of working full-load current.

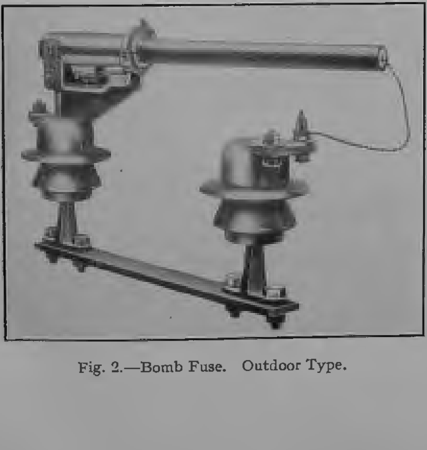


Fig. 2.—Bomb Fuse. Outdoor Type.

HORN FUSE—OUTDOOR TYPE.

6000 Volts (See Section 12)

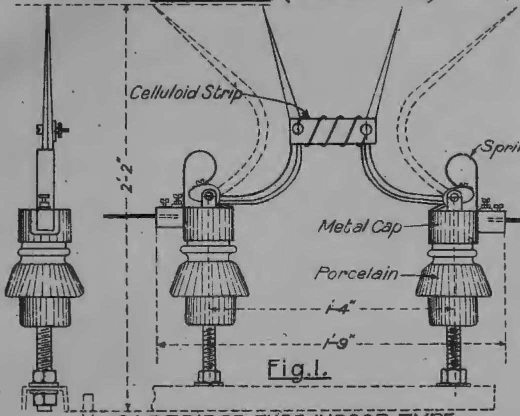


Fig. I.

CARTRIDGE FUSE—INDOOR TYPE.

6000 Volts 100 Amperes.

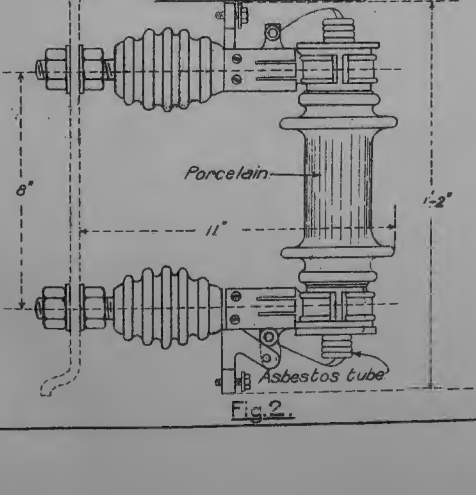
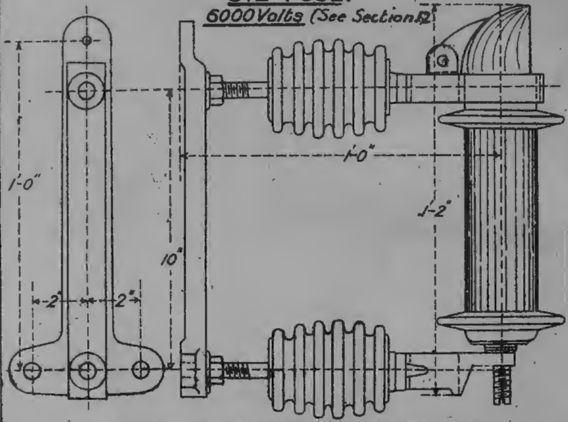


Fig. 2.

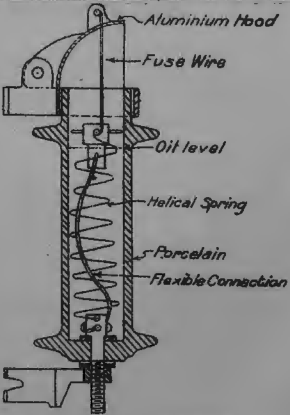
Plate 14.

OIL FUSE.

6000 Volts (See Section 12



SECTION THROUGH OIL RESERVOIR.



broken in case of a fault. This may cause dangerous surging, and, moreover, it may constitute a danger owing to the fact that the circuit is left alive on the other lines. Other disadvantages are their low rupturing capacity and the necessity for handling them to replace blown fuse wires. In spite of these drawbacks, however, fuses are so much cheaper than circuit breakers that they will often be used for financial reasons when dealing with small amounts of power, particularly in temporary installations.

A number of types likely to be met with are described below.

9. **Indoor types of H.V. fuse.**—(i) *Cartridge type* (Pl. **13**, Fig. 2).—In this, the simplest type of fuse holder, the fuse wire is contained in a porcelain tube. The enclosure of the fuse wire causes it to blow with an explosive effect which tends to extinguish the arc. An asbestos liner acts as a buffer.

ii. *Oil type* (Pl. **14**).—In this type the fuse wire is kept in tension by a spring and one end is thereby automatically submerged when the fuse blows. The fuse wire itself should not be normally under the oil. This type is superior to the cartridge type in that the arc tends to rupture when the current is zero, as in an oil circuit breaker.

The above types are suitable for indoor sub-station use as power transformer fuses. In permanent work they may be used for maximum working currents of 5–6 amperes at 3,300 volts. In temporary work they could be used for much larger currents without incurring any great risk, but their rupturing capacity is not large. They invariably destroy themselves in clearing dead short circuits and they should never be used for overhead line protection work.

Silver is the best metal to use in these H.V. fuses as it will carry 65 to 70 per cent. of its fusing current indefinitely without deterioration. To prevent mistakes it is a good practice to use a standard size of silver fuse wire, which may conveniently be that suitable for a working current of 3 amperes, and to use two or more strands for larger currents. If silver is not available, copper may be used as a temporary measure, but it is not advisable to use lead or tin as there is a much larger quantity of metal to volatilize when the fuse blows. It will usually be found necessary to use copper wire on the L.V. side of transformers, especially if the distribution is overhead. The heat capacity of tin fuses is so much greater than that of silver fuses (*see* Pl. **12**) that the latter will invariably be found to go first when the L.V. fuse is tin and the H.V. silver.

Nickel silver is sometimes used for very small currents below 3 amperes when the H.V. fuse is intended as a simple overload fuse. Generally the L.V. fuses or circuit breakers are relied upon for overload protection, and the H.V. fuses are intended to prevent faults in the transformer from affecting the system rather than to protect the transformer itself.

10. **Outdoor types of H.V. fuse.**—In overhead line work, fuses are often used, not as ordinary overload fuses, but for localizing the effects of short circuits on branch lines carrying small amounts of power. They should, therefore, have a large rupturing capacity.

i. *Horn type* (Pl. **13**, Fig. 1).—This is one of the oldest and simplest designs. Two horns are kept in position by a strip of celluloid against the pull of springs tending to open them. The fuse wire is wound round the celluloid and the latter burns when the fuse blows. The action of the horns is explained in Sec. **11**, para. **7**. A disadvantage of this type is that the current tends to break at its peak value.

ii. *Expulsion or " bomb " type* (Pl. **12**, Fig. 2).—This type comprises a brass " explosion cylinder " attached to a length of stout bakelite tube. The inside of the tube is thickly lined with special porcelain cement. A single length of lead wire forms the connection between the outside terminal and a screwed plug in the end of the explosion chamber. The wire is doubled except for the last two inches or so in the explosion chamber. When this latter part fuses, an explosion takes place in the brass chamber and the gases shoot along the bakelite tube and out through the mouth. The circuit is thereby broken very rapidly and effectively. The overall dimensions of a fuse for 11,000 volts 25 amperes is approximately 18 inches long and 13 inches high. Tests show that this size will rupture a short-circuit current of 2,000 amps. within the first cycle of fault duration.

iii. *Carbon tetrachloride type* (Pl. **15**).—This consists essentially of a fuse element connected to a spiral spring within a glass tube which is filled with carbon tetrachloride, a transparent, non-inflammable liquid of high dielectric strength. The fusible element is contained in a special chamber in the upper ferrule (Pl. **15**, Fig. 1). The arcing terminal fits closely through a hole in a supported insulating washer. A " strain " wire, which is a high-resistance wire of high tensile strength and which carries practically no current when the fuse element is intact, passes through a hole in the arcing terminal and is fastened by means of screws to take the pull of the spring.

The low-resistance fuse element is also connected between the arcing terminal and the upper ferrule. When the fuse element blows, the strain wire follows and the arcing terminal is pulled down by means of the spring which contracts to about

"EMPIRE" HIGH-VOLTAGE CARBON TETRACHLORIDE FUSE.

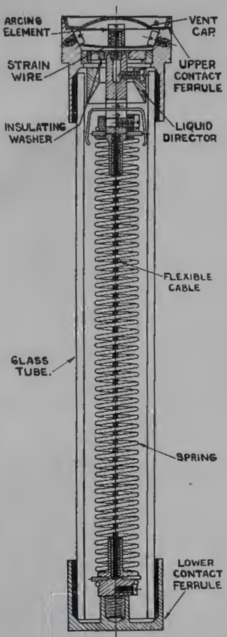


Fig. 1.

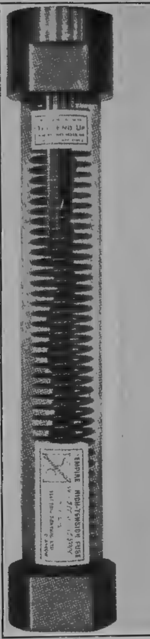


Fig. 2.

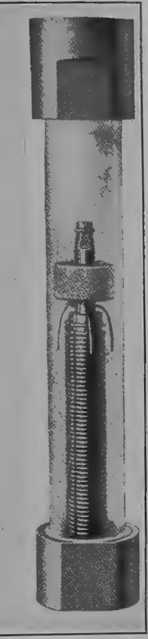


Fig. 3.

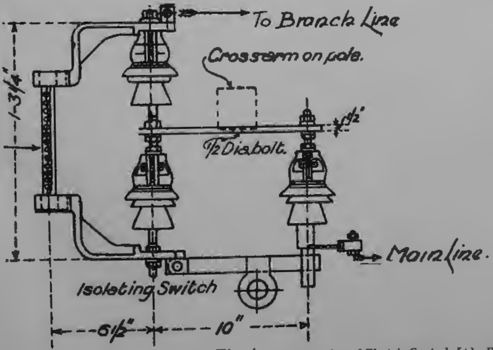


Fig. 4. [Permission of Electric Control, Ltd., Brighton.

one-half its original length. The liquid is forced on to the arcing terminal by the liquid director and the arc is effectively extinguished, in a cycle or so, at the zero point of the current wave. The explosive effect is confined to the chamber between the insulating washer and the thin brass vent cap which is normally gastight (the liquid being very volatile). The vent blows off on the occurrence of a short circuit thus preventing excessive pressure on the glass tube. Pl. **15**, Fig. 2, shows a fuse intact, and Fig. 3 its appearance when it has blown. When mounted on a pole, a blown fuse can easily be detected from the ground.

This type of fuse has a very large rupturing capacity and is definitely superior to all other types in this respect, and, moreover, it disconnects a fault more quickly and with less disturbance of the system. But its initial cost is high, as is also the expense of rewiring, for which purpose it has to be returned to the factory.

Pl. **15**, Fig. 4, shows a method of mounting the carbon tetrachloride fuse on a pole. The dimensions given are approximate only and apply to a fuse rated at 6,600 volts 50 amperes, which the makers recommend for use on a circuit whose maximum working current is 15 amperes. The length of the fuse itself is 9·75 inches (for higher voltages the fuses are longer). The rupturing value of this size is stated to be in excess of 5,000 amperes.

The fuse should be installed in a vertical position, or at an angle not less than 45° from the horizontal, so that the fusible element is not immersed in the liquid under working conditions. There should be no obstruction immediately above the fuse.

13. *Circuit breakers (automatic switches).*

Fuses are not altogether satisfactory and they have been largely superseded by circuit breakers, which usually combine the functions of switches and fuses. No hard-and-fast rule can be laid down, but on L.V. and M.V. circuits the cost of a circuit breaker is generally justified for currents above 100 amperes.

1. **Air break circuit breakers** (B.S.S. 110). The main contacts generally consist of two copper blocks, bridged by a laminated copper brush. The current density per square inch of surface contact is about 200 amperes per square inch for ratings up to 1,000 amperes. This brush is actuated by hand for closing purposes, but electro-magnetic mechanism is provided to open the contacts, *i.e.*, to trip the switch, in the event of abnormal conditions occurring.

In order to prevent damage to the main contacts, due to the formation of an arc when the circuit is broken, one of two devices is adopted, viz :—

(*a*) Auxiliary carbon break.
(*b*) Auxiliary metal break, with magnetic blow-out.

(*a*) is the more common in switches of moderate capacity for switchboard work. The carbon contacts are gradually destroyed, but are easily and cheaply replaced.

(*b*) is always used in switches of large capacity and in switches of all sizes when the circuit breaker is in a confined space.

Pl. **16**, Fig. 1, shows a S.P. 500-volt 300-ampere circuit breaker with auxiliary carbon breaks, and Pl. **17**, Fig. 1, a D.P. circuit breaker of similar capacity with magnetic blow-outs. The overall dimensions are S.P. 8″ × 20″ × 10″, and D.P. 14″ × 20″ × 10″, approximately.

It may here be remarked that although the laminated brush contact is still the most common, a " line contact " type of circuit breaker is being developed in which advantage is taken of the self-aligning property of " V " edged blades bedding in grooves. The rating of this type is about 60 amperes per inch of line contact.

Air circuit breakers are always used in D.C. work, but for reasons given below they are seldom used on A.C. circuits except perhaps for quite small currents.

B.S.S. 110 deals with air break circuit breakers on voltages up to 660. They are rated on their maximum current-carrying capacity, which is the maximum current they can carry continuously with a temperature rise not exceeding 30° C. (up to 100 amps. 20° C. only). An upper temperature limit is also specified for the trip coils, but for this and other details, reference must be made to the standard specification. The test voltage specified is 1,000 volts plus twice the rated voltage with a minimum of 2,000 volts. No standard figures are yet specified for the breaking capacity.

2. **Oil circuit breakers.** (B.S.S. 116.)

The principal reasons for the general use of oil circuit breakers in A.C. work are as follows :—

(1) They tend to break the circuit at a zero point of the current wave, when the oil, in displacing the arc gases, prevents the arc from re-establishing itself between the contacts when they have separated a certain distance in the oil. This distance depends upon the line voltage, and is of course relatively short for ordinary commercial voltages. The arc is more persistent when the power factor is low since the zero points in the voltage and current waves do not coincide, but the oil immersion favourably affects the action in any case

PLATE 16. **AIR BREAK CIRCUIT BREAKER.** [*To face p.* 52.

Fig. 1.—S.P. 500 Volts, 300 Amps. with Auxiliary Carbon Contacts.

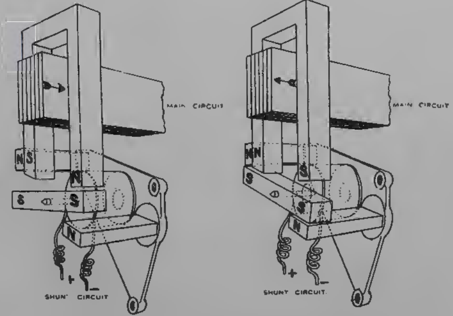


Fig. 2.—Principle of Reverse Current Release.

[Permission of General Electric Co., Ltd.

PLATE 17.

AIR BREAK CIRCUIT BREAKER.

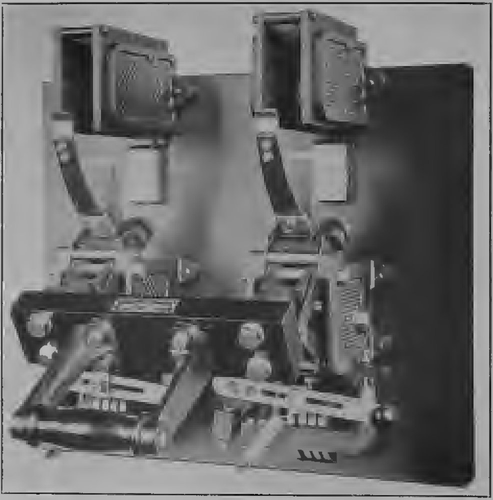
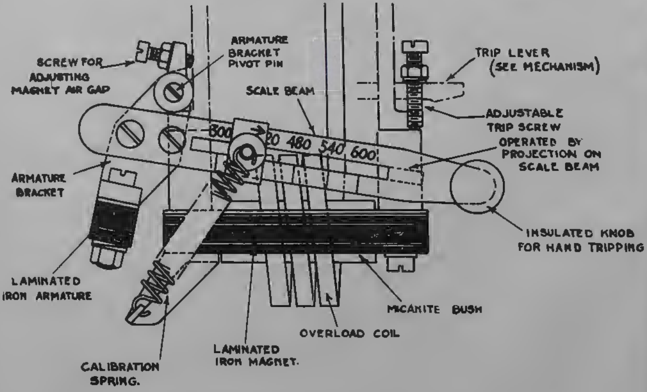


Fig. 1.—D.P. 500 Volts, 300 Amps. with Magnetic Blowouts.



OVERLOAD TRIP.

Fig. 2.

[*Permission of General Electric Co., Ltd.*

On the other hand, with air circuit breakers the tendency to rupture is strongest when the current and electromagnetic blow-out effect is a maximum and dangerous surges may be set up when the arc is suddenly broken.

(2) It is possible to construct oil circuit-breakers of moderate dimensions with a large rupturing capacity. Air break circuit breakers require large clearances for the arc.

(3) Incidentally the oil immersion increases the conductivity of the contact, which is moreover always at maximum efficiency since there can be no oxidation of the metal.

Except for special situations, such as collieries where the atmosphere may become explosive, there is no advantage in using oil circuit breakers on D.C. circuits. There is no zero point, and the arc is more persistent and consequently the same length of break is required in oil as in air. The D.C. capacity of an oil circuit breaker is less than one-half its A.C. capacity.

The principle of the oil break involves the use of an oil bath in which both fixed and moving contacts are submerged. The contacts are generally made between wedge-shaped copper blades, and a double set of self-aligning contact fingers backed by strong steel springs.

In modern designs a definite " line " contact under considerable pressure is aimed at rather than a large area of " surface " contact, and the ratings appear to be based upon about 100 amperes per inch of line contact at 6,600 volts.

The direction of movement of blades is always vertical. This enables gravity to assist the opening operation, involves minimum displacement of the oil and concentrates the effects of rupture in a vertical plane. It is to be noted that oil circuit breakers do not depend upon oil circulation, but have to deal with explosive forces developed in the region of the break.

Oil circuit breakers are rated on voltage and maximum current-carrying capacity, which is the maximum current they can carry continuously with a temperature rise measured at the hottest part of the oil of 30° C. (above 4,000 amperes rating, 40° C.).

No standard figures are yet specified for rupturing capacity, but with modern design it may be taken as about ten times the carrying capacity.

The dielectric test voltage for working voltages up to 1,000 is 1,000 plus twice the rated voltage with a minimum of 2,000 volts, and for voltages above 1,000 the test voltage is 2,000 plus 2½ times the rated voltage. For further particulars reference must be made to the standard specification.

Pl. 18, Fig. 1, shows a direct hand-controlled 3-phase oil circuit breaker for mounting at back of panel, suitable for 600 amperes at 6,600 volts or 300 amperes at 11,000 volts. The contact blades are at right angles to the control panel. Fig. 2 shows the contacts of a circuit breaker of similar capacity with the blades parallel to the control, which may sometimes be more convenient. Fig. 3 gives some idea of the dimensions. As usual, a double break per pole is provided to reduce the travel of the contact blades for a given clearance in the " off " position. Renewable sparking fingers are provided to minimize damage to main contacts when opening under severe conditions. Accelerating springs are provided to give the correct speed of break, and the shock is absorbed at the end of the opening stroke by means of buffer springs. A pebble-filled chamber and gas vent (C, Figs. 1 and 2) is fitted to relieve the pressure set up by the gas generated during the operation of the breaker under a heavy fault. The gas and oil vapour are carried to this chamber, where the separation of the oil and the cooling of the gas takes place. The gas passes through the vent while the oil drains back into the tank.

Oil circuit breakers are largely used on all voltages, and can be obtained for ratings as low as 40 amperes at 660 volts. Naturally the requirement for M.V. circuits are less onerous, and the designs are much simpler.

In stations of small capacity the circuit breakers may be hand-operated with direct or remote control; with direct control the circuit breaker is placed behind the panel, whereas with remote control it may be put in any convenient position and worked through links and bell-crank levers. Circuit breakers of large capacity are installed in basements or special buildings and operated by electrical remote control.

When a number of oil circuit breakers are located in the same station they should all be of the same size, and should be capable of dealing with the full capacity of the station. Also, there should be complete interchangeability to reduce the number of necessary spares. Isolating switches should be installed to isolate oil circuit breakers during overhaul and repairs.

3. Automatic operation of circuit breakers.—It is usual to make the automatic opening operation quite independent of the manual closing operation. This so-called *free-handle* mechanism enables a circuit breaker to be used without a knife switch in circuit with it, as the contacts cannot be held closed if there is an abnormal disturbance in the line controlled.

Compared with fuses, electro-magnetic cut-out devices

PLATE 18.

[To face p. 84.

OIL CIRCUIT BREAKER.

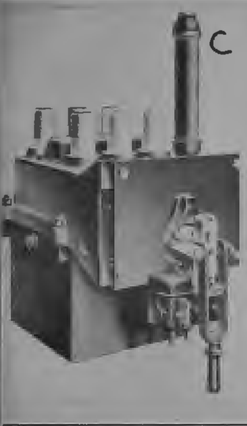


Fig. 1.

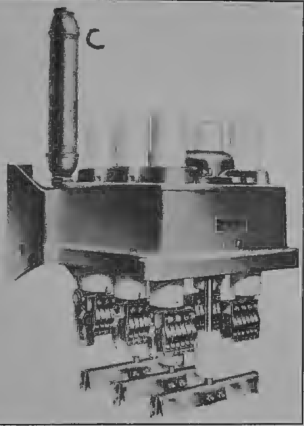


Fig. 2.

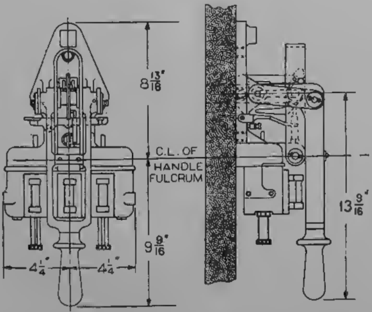
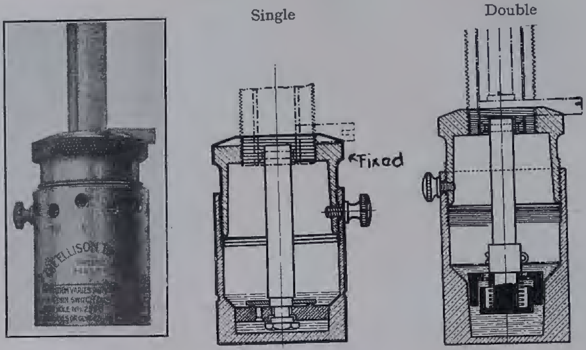


Fig. 3.

[Permission of The British Thomson-Houston Co., Ltd.

ELLISON DASH-POT TIME LAG.



(a) (b) (c)

Fig. 1.

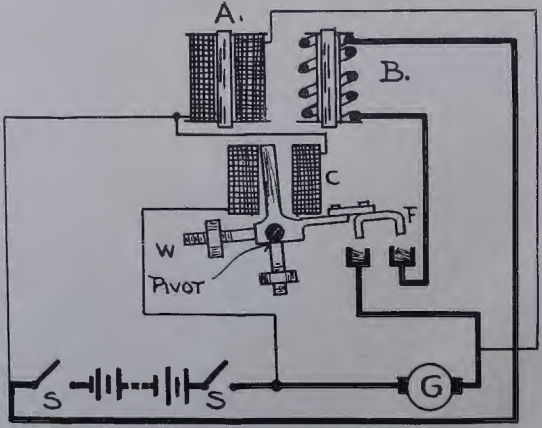


Fig. 2.—Principle of Crawley Cut-out.

have the following advantages, which become of greater importance as the amount of energy increases :—

(*a*) The value and duration of the opening current can be more accurately predetermined.
(*b*) It is cheaper and quicker to re-establish the supply.
(*c*) There is no danger of fire owing to the scattering of molten metal, especially when a dead short circuit occurs.
(*d*) They can be arranged to function on reversal of current or failure of supply, as well as on excessive current, which is the only abnormal condition that fuses can guard against.
(*e*) All lines of supply may be broken simultaneously.

All apparatus and circuits must naturally be provided with overload protection. Single generators need overload protection only, but when a number of generators are working in parallel it is necessary to provide ***reverse-current*** protection to prevent a faulty engine from being motored from the bus-bars. Feeders should have leakage protection at the supply end and overload protection at both ends, and when there is a possibility of power being fed back from the delivery end of the feeder (which might occur where there is a secondary battery installed in a sub-station) it is essential to provide ***reverse current*** protection as well. *No-volt* protection is frequently provided by circuit breakers to ensure the opening of the circuit if the supply fails. Such protection is especially necessary for D.C. motors, and is desirable for all motors.

4. **Time lag.**—Where overloads are likely to be frequent, as in power work, but of such a duration as to occasion no danger, it is advisable to fit the tripping arrangement with a time lag element.

In both A.C. and D.C. work this may be effected by fitting the armature with an oil dashpot.

Pl. **19,** Figs. 1 (*a*), (*b*), and (*c*), illustrate the Ellison dashpot type of time lag. The oil level with the piston in position is about a quarter of an inch higher than shown in the figures. Over the working range of adjustment the cylinder is tapered. Below the tapered portion the cylinder well has parallel sides, but the piston itself is also slightly tapered. When the piston is pulled upwards, the tendency to the formation of a void retards the motion and the speed of movement is determined by the rate at which the oil can flow past the piston to fill the void. In the position shown, which corresponds with the longest time setting, the only passage for the oil is through three small holes in the piston, but if the cylinder is lowered, an annular passage between the piston and cylinder is opened, the rate of oil flow is increased, and the time required to pull up the piston therefore reduced. Eleven settings are provided, and a side screw serves to lock the cylinder in the desired setting. If the range of adjustment does not meet requirements with thin oil, a thick oil or glycerine should be tried.

For the " straight on " starting of squirrel-cage induction motors the Ellison " double " time lag (Fig. 1 (*c*)) was introduced. This is a modification of the type described above in which an auxiliary spring loaded piston is provided to close the holes in the main piston under the relatively heavy pull caused by the motor starting current, and this action has the effect of increasing the time of retardation long enough for the motor to run up to speed.

When the heavy starting current has subsided, the spring extends, the holes in the piston are uncovered, and the piston acts in the ordinary way on normal overloads.

5. Automatic operating devices in D.C. circuits.—These consist of simple solenoid operated trips, and call for little comment.

i. *Overload trip.*—An enlarged view of the overload release fitted to the circuit breaker shown in Pl. **17**, Fig. 1, is given in Fig. 2, which is self-explanatory.

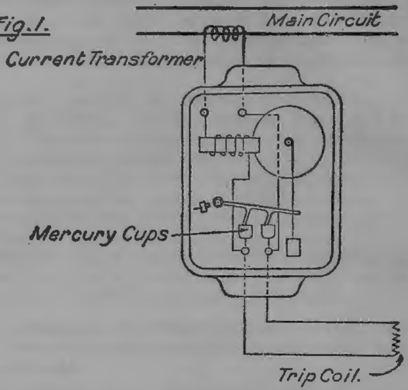
ii. *Reverse current trip.*—The principle of a reverse current trip will be gathered from Fig. 2 on Pl. **16.** The pivoted armature SS is polarized as shown by a coil connected to the bus-bars. When the main current is "forward," *i.e.*, in the correct direction, this armature is rotated counter-clockwise by the action of the vertical horse-shoe magnet. When the main current reverses in direction the armature rotates clockwise, and an extension thereon trips the circuit breaker.

iii. *Crawley reverse current cut-out.*—Pl. **19**, Fig. 2, gives a diagram of the connections of the " Crawley Cut-out," which is one of the best types of cut-out for use in the charging circuits of secondary batteries.

When the supply is " off " the copper fork F is kept clear of the mercury cups by means of the balance weight W. There are three solenoids A, B, and C. On closing the switches SS, the coil C is energized directly from the battery, and its polarity is therefore definitely fixed. Coil A is excited by a current depending for its direction on the difference between the dynamo and battery voltages. When the former exceeds the latter by a few volts, the core of C is repelled from A and the fork enters the mercury cups and closes the charging circuit. Coil

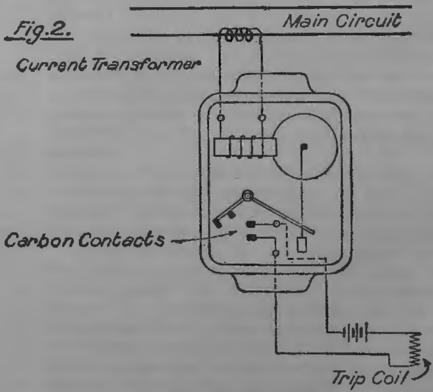
OVERLOAD RELAY.

Fig. 1.



Connections for tripping with A.C.
Mercury cup contacts used to open Trip Coil Circuit.

Fig. 2.



Connections for tripping with D.C.
Carbon contacts used to close Trip Coil Circuit.

B carrying the main charging current then strongly attracts the core of C, and holds the fork in. It will be noted that the coil A is short-circuited by the coil B. If the dynamo voltage falls the attraction of B decreases, and when the current is reduced to a certain minimum, depending upon the position of the weight W, the torque due to the latter predominates, the fork is pulled out of the cups, and the circuit broken before a reversal of direction of current can take place.

6. Automatic operating devices in A.C. circuits.

i. *Overload protection.*—For overload protection the trip coils may be either direct-acting or operated through relays. When direct-acting they may be placed directly in the circuit to be protected, but it is more usual to connect them through current transformers. When relays are used, arrangements can be made for the trip coils to be energized either from the A.C. circuit itself (Pl. **20**, Fig. 1), or from an independent D.C. supply (Pl. **20**, Fig. 2). In either case the action of the circuit breaker mechanism is more definite and positive than with direct-acting arrangement.

ii. *Time lag.*—When direct-acting the circuit breaker will trip instantaneously on the occurrence of an overload in excess of that for which the plunger has been set. (By instantaneous is meant something in the neighbourhood of one-tenth of a second.)

In the majority of cases, however, it is desirable to introduce a time lag in the operation of the overload trip coils to prevent them from functioning on momentary overloads which are not of sufficient duration to cause excessive heating of mains and machinery. This lag is sometimes introduced by shunting the trip coils by a fuse (*see* Pl. **21**, Figs. 1 and 2), the inverse time element of which has been pointed out in Sec. **12**, para. **7** (1). On normal full load about **95** per cent. of the current flows through the fuse; but more often the trip coil is placed in a local circuit, and an adjustable mechanical device is fitted to the relay to give it the required delay action. This arrangement is more definite in its adjustment and calibration than a fuse, and, moreover, a discriminating action is obtainable, *e.g.*, when two trip coils are in series, one at each end of a feeder, one can be adjusted to act definitely before the other. Fuses are not suitable for this purpose.

Pl. **21**, Fig. **3**, shows a 2-pole relay of the shaded-pole induction type for A.C. work. The relay consists of a pivoted copper or aluminium disc which can rotate between the poles of an electro-magnet with laminated core energized from the main A.C. circuit through a current transformer. The poles of this electro-magnet are tipped with a copper ring, and a torque is set up in the disc which is resisted by a weight suspended from a cord passing over a small pulley upon the disc spindle. When the current reaches a certain value, the torque is sufficient to raise the weight, and the disc rotates. A permanent magnet, near the circumference of the disc, acts as a brake. As the weight gets near the top of its travel it engages with a lever, which actuates the relay contacts. There are two adjustments, one for percentage overload, and the other for the amount of time lag. The first is obtained by altering the value of the suspended weight (usually 50, 75, and 100 per cent. overloads are provided for), and the second by altering the length of the cord.

iii. *Number of overload trips required on 3-phase circuits.*—If the neutral is insulated, two current transformers and two overload trips are sufficient for simple overload protection. If the neutral is earthed, 3 transformers and 3 trip coils are necessary, either 3 overload trips, or 2 overload trips and 1 leakage trip.

iv. *Reverse power protection.*—Generators should be provided with reverse-power protection. The induction-type relay (described in para. ii for overload protection) can also be used for reverse-power protection if a voltage coil be added; it then acts exactly as an induction-type wattmeter. When the current has a component in phase with the voltage, the disc tends to rotate in a clockwise direction, but its motion is arrested by a stop. When the current is more than 90° out of phase with the voltage, the disc runs backwards away from the stop, and, revolving freely, winds up the weight until the trip-coil circuit is closed. In Pl. **35**, two reverse-power relays are shown, the current coils C_1 C_2 and the volt coils V_1 V_2.

v. *Leakage protection.*—The introduction of leakage protection necessitates working with the neutral earthed. Pl. **22**, Fig. 1, is a diagram of connections of one system. So long as the current carried by any one of the three phases returns by the other two, the

TIME LIMIT FUSE.

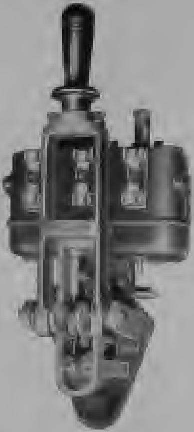


Fig. 1.—Time Limit Fuses. Mounted on Oil Circuit-breaker Escutcheon.

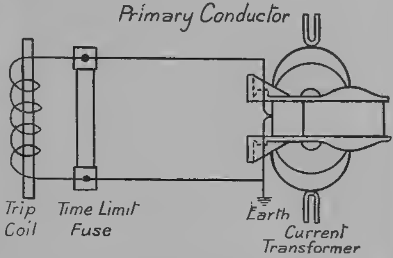


Fig. 2.—Principle on which Time Limit Fuse works.

OVERLOAD RELAY.

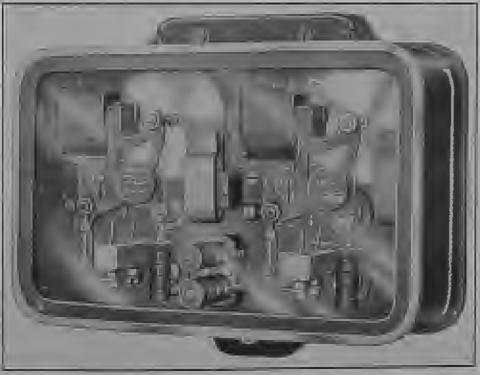


Fig. 3.—2-Pole Induction Type.

[*Figs.* 1 *and* 2, *permission of the British Thomson-Houston Co., Ltd.*; *Fig.* 3, *permission of Messrs. Ferranti, Ltd.*

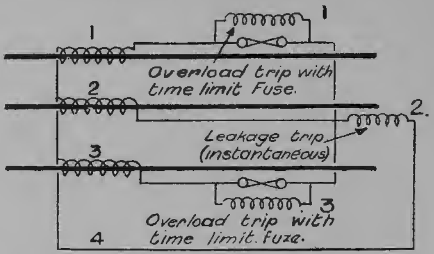


Fig. 1.—Diagram showing Principle of Leakage Protective System.

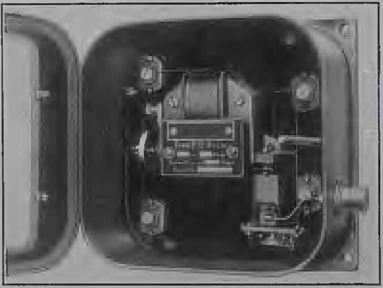


Fig. 2.—Leakage Relay.

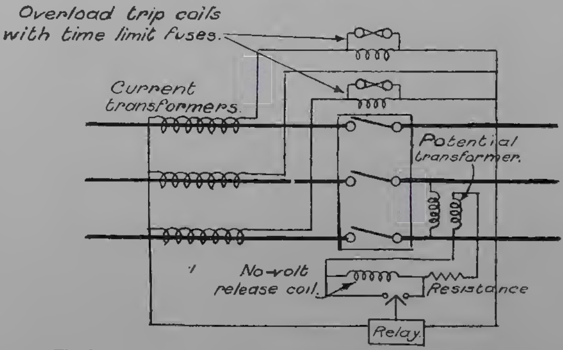


Fig. 3.—Relay Contacts Short-Circuiting a No-Voltage Trip.

[*Permission of The British Thomson-Houston Co., Ltd.*

sum of the currents in the secondary circuit of the current transformers, and therefore in No. 2 trip coil, is zero (*i.e.*, the leakage trip coil is unaffected by load conditions). When leakage occurs, No. 2 trip coil carries an independent current proportional to the fault current. If the leakage trip coil is worked through a sensitive relay instead of directly, a high resistance may be inserted in the neutral earthing connection. Pl. **22**, Fig. 2, shows a suitable relay consisting of a sensitive electro-magnet, the armature of which closes a local circuit in the usual way. This relay can be adjusted to act with a fault current of less than 10 per cent. of normal full-load line current. Pl. **22**, Fig. 3, is a diagram of connections in which the relay contacts short-circuit a no-voltage trip.

vi. *Other protective devices.*—There are many other forms of protective device in use on extensive A.C. networks, but military systems are seldom of sufficient magnitude to require anything more than simple overload and leakage protection.

7. Oil break switch fuses.—As a cheaper alternative to the normal type of oil circuit breaker with electro-magnetic trip coils a number of designs of oil break switch fuses have recently been introduced, which will satisfy most requirements of transformer protection up to, say 500kVA at 11,000 volts. The automatic feature is obtained by means of a spring loaded fuse element, the energy stored up in the spring being used to actuate a tripping mechanism. In the 3-phase type, a fuse blowing on one phase is sufficient to trip the switch which breaks under oil on all three phases simultaneously, thus obviating the disadvantage of simple fuses which may isolate one line only. With this apparatus it is possible to break the full load of the transformer with safety by hand, and the fuse will deal with faults up to about 25,000kVA. They are made for either indoor or outdoor use, and are frequently used in outdoor kiosks.

14. *Bus-bars and connections.* (*B.S.S.* 158 *and* 159.)

1. Bare back switchboard connections are generally to be preferred, supported by insulators on iron brackets. Either copper or aluminium may be used, the maximum current density allowed in the former being 1,000 and in the latter 650 amperes per square inch, providing that the temperature rise of the bus-bars above the surrounding air does not exceed 30° C. for single and 35° C. for multiple bars. For the moderate sizes required for most military purposes single strip bars will usually suffice, but when dealing with thousands

of amperes it is necessary to use a number of ¼-inch thick strips in parallel.

Aluminium offers the advantages of light weight and large radiating surface, and comes out cheaper when its price per pound is less than twice that of copper.

2. **Duplicate bus-bars** are sometimes provided in commercial work, but are rarely justified for military purposes.

Their advantages are :—

(1) For running up a new or doubtful machine on to an independent or test circuit.
(2) For making extensions (one set of bus-bars can be made dead at a time).
(3) When running a system with two different voltages.
(4) For cleaning purposes.

Item (4) may be disregarded with iron-clad switchgear.

3. **Clearances between bus-bars and connections of different polarity.**

Up to 650 volts 500 amperes, 2 inches minimum.
Up to 650 volts above 500 amperes, 3 inches minimum.
3,300 to 6,600 volts, 6 inches.

Clearances between live parts and switchboard frame.—(Except at bushed holes.)

Up to 650 volts, 1½ inches minimum.
3,300 to 6,600 volts, 3 inches minimum.

4. **Bus-bar supports.**—Electromagnetic attraction or repulsion between bars may reach appreciable values on heavy short circuits, and for this reason they must be securely fixed. Relatively light bars may be supported as shown in Pl. **23** at A, but the method shown at B is generally better as it allows for thermal expansion (100 feet length of copper bar expands about 1 inch for 50° C. rise in temperature).

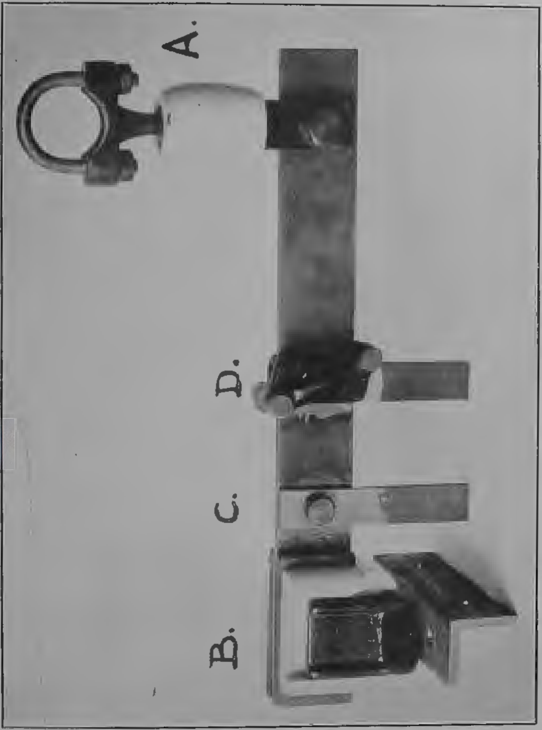
5. **Joints and connections.**—The contact surfaces of all copper lap joints must be tinned, and in the case of aluminium they should be lightly coated with vaseline and scratch brushed. The length of the overlap for copper strip should not be less than the following :—

¼-inch thick, 2 inches long.
⅛-inch thick, 1½ inches long.
$\frac{1}{16}$-inch thick, 1¼ inches long.

For aluminium bars the overlap should be somewhat longer. Generally speaking the lengths necessary for bolting the strips together are greater than the values given here. Pl. **23** also shows alternative methods of joining vertical strip connections to the bus-bars. D is preferable to C for large currents. One of the clamping bolts at D should be of brass

PLATE 23.

[To face p. 60.



BUS-BAR SUPPORTS.

on A.C. boards to break the magnetic circuit, and so prevent excessive heating in the clamp due to eddy currents and hysteresis.

6. **Cable connections.**—As little ordinary rubber-covered cable as possible should be used on a switchboard, owing to its inflammability. If the connections cannot be bare they should have a fireproof covering over the insulation. All sweated connections should be relieved of mechanical stress. Long lengths of heavy cable must not be hung from switch and circuit-breaker studs. Every endeavour should be made to bring cable connections to the top or bottom of a switchboard.

7. **Small wiring.**—Erection and maintenance is greatly facilitated if small wiring is fixed rigidly to the back of panels in *diagrammatic manner*. The connections should be as short as possible, the old practice of leaving a little slack coiled up near each terminal being unsightly and dangerous. Crossing of wires should be reduced to a minimum. Conductors should be solid and not less than 14 S.W.G., which is sufficiently rigid to enable a neat appearance to be maintained with a minimum number of cleats. The insulation should be of high-grade V.I.R. with an asbestos braid serving (self-extinguishing type) of appropriate colour. The wires should be secured by two-piece porcelain cleats, and all terminals should be provided with suitable connecting lugs and washers.

Remember always that the quality of a switchboard is better judged from the back than the front.

8. **Marking.**—Bus-bars and connections should be coloured to indicate the pole or phase to which they belong, and the colouring must be uniform throughout the system on both H.V. and L.V. The standard marking is briefly as follows :—

D.C. { Positive . . . Red. Negative . . . Blue.
Midwire . . . Black if earthed, Green if unearthed.

A.C. 3-phase . . . Red, White (or Yellow), Blue.

The order of the national colours indicating the order of phase rotation.

Neutral . . . Black if earthed, Green if unearthed.

There is also a standard arrangement of the coloured connections, *e.g.* Horizontal 3-phase bus-bars should be arranged red nearest the switchboard and yellow in the middle. For further particulars, *see* B.S.S. 158.

9. **Insulation.** (*See* B.S.S. 160 for slate).

It may be repeated that all material used should be as far as possible non-hygroscopic and non-inflammable. As much dry air should be used as possible, and no solid insulation should be required for the main connections except at points of support and at thoroughfare connections to instruments. Porcelain, mica, micanite and ebonite have been most largely used in the past, but fibrous materials impregnated with synthetic resin compounds, such as "Bakelite," are now coming into use, which have many advantages. They are excellent dielectrics, easily worked, strong and tough, being better than ebonite in this respect. They are practically non-hygroscopic and are not carbonized by heat below about 600° F.

Although good quality slate without metallic veins, thoroughly dried and varnished or enamelled, has a high insulation resistance, it is not now considered good practice to rely on it for insulation, but simply as a mechanical support. Therefore non-hygroscopic bushes and washers must be used, or adequate air clearances provided where connections pass through the slate.

10. **Insulation testing.**—Two distinct characteristics of insulating materials have to be considered, viz. :—(1) Resistance. (2) Dielectric strength. The first determines the leakage current, and the second the voltage required to puncture. It is important to distinguish between *volume* insulation resistance and *surface* insulation resistance. Normally it is the latter which determines the insulation resistance of switchboards, and it varies greatly with the amount of apparatus on the board, the temperature and the humidity. When the board is *quite dry*, the insulation resistance between conductors themselves, and between conductors and non-current-carrying metal work should not be less than 10 megohms per panel when tested with a 500-volt megger.

But the real criterion of the effectiveness of the insulation is the high voltage test. The complete switchboard with instrument cases earthed should withstand the application of the following A.C. voltages applied for one minute :—

Up to 650-rated voltage, 2,000 volts.
Above 650-rated voltage, 2,000 volts plus 2½ times the rated voltage.

15. *Measuring instruments.*

1. **Types.**—The electrical measuring instruments commonly met with in practice may be classified as follows :—

i. *Sub-standard instruments.*—These are high-grade portable indicating instruments, which are calibrated by means of primary standards, *e.g.*, a Kelvin balance, or a potentiometer and standard cell, and can then be used to check the accuracy of commercial instruments conveniently and quickly. Permanent-magnet moving-coil instruments are used as D.C.

sub-standards, and dynamometer moving-coil instruments as A.C. sub-standards.

ii. *Commercial instruments.*—These are the ordinary switchboard and portable instruments, which are calibrated by means of the sub-standard instruments. They may be grouped as follows :—

(*a*) *Indicating* instruments, such as ammeters, voltmeters, wattmeters, P.F. meters, and frequency meters.

(*b*) *Recording* or *graphic* instruments, which include such indicating instruments as have a pen attached to the pointer to enable a continuous record to be made.

(*c*) *Integrating* instruments, commonly known as *electricity supply meters*, which enable the consumption of electrical energy to be measured for costing purposes.

2. **Ammeters and voltmeters.**—Ammeters have the whole of the current to be measured passing through them, and, consequently, they should have as low a resistance as possible. Voltmeters, on the other hand, are connected in shunt across the mains, and should have as high a resistance as possible. Subject to this reservation they are identical in principle.

It should be noted that voltmeters and, similarly, the voltage coils of all instruments should always be connected through fuses.

i. *Moving-coil instruments (permanent magnet type).*—In this type of instrument the pointer is attached to a light metal frame, which is pivoted between the poles of a strong permanent magnet. A coil of fine copper wire is wound on the frame, and the movement is due to the torque produced by the interaction of the two fields, viz., that of the permanent magnet and that produced by the current in the coil. Since the field of the permanent magnet is constant the deflection is directly proportional to the current in the coil, and the *scale* is, therefore, *one of equal divisions.*

These instruments can be used in D.C. work only ; since a reversal of current also reverses the direction of rotation of the coil, they can be made to have the zero point at the centre of the scale.

Connections to the moving coil are made by light springs, which also, in most designs, control the movement. Damping is effected by the eddy currents induced in the metal frame, which is usually aluminium. The case of the instrument is generally of iron, the movement being thereby screened from the disturbing effect of external magnetic fields.

Instruments of this type do not permit of a current of more than 0·1A being passed through the moving coil ; consequently, when an instrument is used as an ammeter a shunt has to be employed to carry the main portion of the current to be measured. In reality the indicating part of the instrument is a milli-voltmeter, and most modern designs arrange for a full-scale deflection with **75mV.** The reading is proportional to the voltage drop across the shunt, and, therefore, to the current flowing through the shunt, so the scale can be calibrated in amperes ; the effect of temperature variations is avoided by making the shunt of manganin or other alloy with a negligible temperature coefficient.

The indicating portion of the instrument is the same for both ammeter and voltmeter, but in the latter a high non-inductive resistance with a negligible temperature coefficient, has to be connected in series with the working coil.

The same indicator can be used for any other range of volts and amperes by the substitution of series resistances or shunts of suitable values.

ii. *Moving coil instruments* (*dynamometer type*).—In this type the current to be measured passes through two coils, one fixed, and the other movable. It is a square-law instrument, and can therefore be used on both A.C. and D.C. The type is seldom met with in switchboard work.

iii. *Moving iron instruments*.—In this type the pointer is fixed to a piece of soft iron, which is pivoted in the field of an electro-magnet. The latter is energized in the case of ammeters by a coil carrying the actual current to be measured, and in the case of voltmeters by a large number of turns of fine copper wire, connected in series with a relatively large non-inductive resistance, the temperature coefficient of which is negligible.

The resulting movement will be proportional to the product of the field strength and the magnetic induction in the iron, and the latter is itself proportional, at low flux densities, to the strength of the field. But the field strength is proportional to the current in the coil, so the torque produced is approximately proportional to the square of the current, and the *scale* is consequently one of ***unequal divisions.***

The scale is unduly crowded in the lower portion, and the readings, which are less than about one-quarter of the maximum scale reading, are of little value. This is, of course, typical of all *square-law* instruments.

These instruments can be used equally well for A.C. or D.C. work. They should, preferably, be calibrated with the type of current for which they are to be used, but good modern types read practically the same on A.C. or D.C. An exception must be made, however, in the case of low-reading voltmeters, in which the inductance of the working coil is relatively large compared with the total resistance of the instrument.

Switchboard instruments are frequently gravity-controlled, but portable instruments must necessarily be spring-controlled. For Service purposes, however, G.D.E.S. No. 3 requires all ammeters and voltmeters to be spring-controlled. Dashpots or other equivalent arrangements must be provided to make them dead-beat, but they are never so well damped as the moving coil-type. Screening from the effects of external magnetic fields is of vital importance, especially on switchboards, and is effected by the provision of an iron case for the instrument.

iv. *Hot-wire instruments* depend upon the heating effect of a current in a conductor, the expansion of the latter being made to give motion to a pointer over a calibrated scale. They follow the *square law*, and can be used with equal accuracy for D.C. and A.C. They are readily damped by means of a permanent magnet acting upon an aluminium disc carried on the spindle of the pointer, and are unaffected by stray magnetic fields and ordinary changes of frequency. On the other hand, they are liable to be rendered inaccurate, if not actually destroyed, by an overload of from 50 to 100 per cent., their calibration is uncertain, and they consume a comparatively large amount of power ; for these reasons they are seldom employed now for lighting and power work.

Their real sphere of usefulness is in the measurement of high-frequency currents in medical and wireless work.

v. *Electro-static voltmeters* depend upon the attraction between two sets of thin metal vanes, connected respectively to the points between which the potential difference is required. One set of vanes is fixed, whilst the other set carries the pointer and is free to move. The force of attraction is directly proportional to the square of the difference of potential between the bodies and to the exposed area, and inversely proportional to the distance between the surfaces.

On account of the large area of vane required, these instruments are not often used for measuring low voltages, but they are particularly suitable for high voltages since they consume no appreciable energy.

vi. *Induction instruments* are dependent upon the mutual effect between eddy currents and can be used for A.C. only. The most common type is that in which an aluminium disc passes between the poles of an electro-magnet, energized by the current or voltage to be measured. Copper screens, or shields, cover rather more than half of the pole faces of the electro-magnet. Eddy currents are formed in the portion of the aluminium disc between the poles, where these are *not* covered by the copper screens, and similar currents are simultaneously produced in the screens themselves. The resultant action between disc and screen causes a continuous drag on the former in one direction, the controlling force being provided by a spring.

vii. *Comparison of various types.*—It is not possible here to discuss fully the advantages and disadvantages of the various types of instrument that have been described; it may, however, be stated that, for D.C. work, the permanent-magnet moving coil instrument is by far the best, and that, for A.C. work, the moving-iron instrument is superior to all other types for ordinary commercial purposes.

3. **Wattmeters.**—The power in a D.C. circuit can always be determined by measuring the volts and amperes and multiplying their values. In A.C. work, however, the power factor has also to be taken into consideration, the true average power being proportional to VI $\cos \phi$. It is possible, therefore, to measure power in A.C. circuits by means of a voltmeter, an ammeter, and a P.F. meter, but the more usual method is to employ a wattmeter, which gives indications of the true power directly in watts.

The two most common types of wattmeters are :—

i. The dynamometer type.
ii. The induction type.

i. *Dynamometer wattmeters* depend upon the spring-controlled reaction between two coils, one stationary and carrying the main current, or a definite portion of it, the other carrying a current proportional to the voltage, and being pivoted so as to be capable of rotation in the field produced by the fixed coil. Damping is provided by a dash pot, and screening by a cast-iron case as usual.

They can be used with equal accuracy on D.C. and A.C. circuits, which is a great convenience since it enables instruments for use on A.C. to be calibrated on D.C.

ii. *Induction wattmeters* are largely used for switchboard work, as they are cheap and robust, and have a long scale. The principle upon which they work is similar to that of induction ammeters and voltmeters (*see* para. 2 (vi)), and, consequently, they can be used on A.C. circuits only. Shaded poles are not, however, necessary, since one set of eddy currents is produced by the current coil, and the other set by the voltage coil. It is, perhaps, more correct to say that the two coils produce a rotating magnetic field, and that the aluminium disc tends to rotate in this field in the same way as the rotor of a squirrel-cage induction motor. Damping is provided by a permanent magnet acting on the disc that is used to produce the deflection.

These instruments are usually fitted in an iron case, but they are only very slightly affected by stray magnetic fields.

Wattmeters for single-phase A.C. circuits have one current coil and one voltage coil, those for 3-phase 3-wire circuits have two current coils and two voltage coils, whilst for 3-phase 4-wire systems with unbalanced load three current coils and two voltage coils are needed.

It is desirable to install wattmeters on all A.C. feeder and machine panels ; on A.C. generator panels they are essential.

4. **Power-factor meters.**—If a wattmeter is installed in any particular circuit the power factor may be calculated from readings of the ammeter, voltmeter, and wattmeter, but it is often desirable to be able to read the P.F. directly. This is particularly important with synchronous motors and rotary converters, and with A.C. generators which are working in parallel.

i. *Dynamometer type.*—The single-phase dynamometer pattern power factor meter has a single fixed current coil and a moving system containing two voltage coils at right angles. By means of a "*phase-splitting*" device, consisting of a resistance in series with one coil and a condenser in series with the other, a rotating field is set up by the two coils of the moving system, and the displacement of the axis of the voltage coil carrying the "*in-phase*" current, from the axis of the series coil, gives the angle of lag or lead of the current.

This type suffers from the disadvantage of requiring conducting ligaments to the moving system, and in consequence the inductor type is now most frequently met with.

ii. *Inductor type.*—In this type there are no connections to the moving system, and therefore a complete 360° revolution is possible. In its simplest form the Single Phase type has two fixed current coils placed at right angles, and the usual phase-splitting device is used to produce a rotating field. The moving part consists of a "Z"-shaped soft iron member, the middle of which constitutes the axis upon which it revolves, and also forms the core of the fixed voltage coil. The polarity of the moving vanes therefore follows that of the voltage coil, and the position taken up indicates the phase angle in the same way as in the dynamometer type.

In the 3-phase type, three current coils are used to produce the rotating field, two current transformers being required in 3-wire and three current transformers in 4-wire systems.

On generator panels the pointer is so adjusted that it indicates on the upper half of the scale with forward currents. Should the generator begin to run as a motor, the pointer will indicate on the lower half of the scale. Therefore the instrument acts also as an indicator of the direction of flow of the energy.

The greatest care must be taken to connect up wattmeters and power factor meters *exactly* according to makers' instruction diagrams sent with the instruments.

5. **Frequency meters.**—Instruments for indicating the frequency of an alternating current are of two kinds, viz. :—

i. Those working on the *ohmmeter principle.*
ii. Those working on the *resonance principle.*

i. depend upon the variation of current, due to the changes of frequency, in an inductive circuit. Two coils, fixed at right angles to one another and carrying the pointer, are connected together, and the junction is also connected to the centre point of a fixed resistance across the mains. The other end of one coil is connected through an inductive resistance to one of the mains, and the other end of the second coil is connected through a non-inductive resistance to the other main. Any increase or decrease in the frequency increases or decreases the reactance, thus altering the current distribution. A very open scale is secured, but the instrument in this simple form is affected by changes of voltage.

ii. depend upon the action of an alternating magnetic field, upon a number of steel reeds, each having a slightly different natural period from the others. The one whose natural period is twice that of the current is set in resonant vibration. If a direct current equal to the maximum value of the alternating current is superposed on it one-half of the alternating wave is neutralized, and the other half is increased, with the result that a reed whose natural period is *equal* to that of the alternating current is caused to vibrate. The same instrument can thus be used for two ranges. A similar result may be obtained by using a permanent magnet in lieu of the superposed D.C. winding, provided that steps are taken to prevent it from becoming demagnetized by the alternating flux.

6. **Watt-hour meters.**—Excluding clock meters, which are now seldom met with, the majority of watt-hour meters are really small electric motors, loaded by means of eddy-current brakes. Current and voltage coils are provided, and the electro-magnets are so designed and disposed that the *driving torque* is proportional to the true power, *i.e.*, $VI \cos \phi$.

The *retarding torque* is provided by an aluminium or copper disc which rotates in the field of a permanent magnet. In the induction type of meter used almost exclusively on A.C. work, both driving and retarding torques operate directly on the same disc. The E.M.F. generated in the disc by rotation in the permanent-magnet field is directly proportional to the speed of the disc S and the *power* dissipated $\propto \frac{E^2}{\rho} \propto S^2$ (ρ being the specific resistance of material of disc).

Also *power* $\propto$ *retarding torque* $\times S \propto S^2$ therefore the retarding torque $\propto S \propto \frac{N}{t}$, if the disc makes N revolutions in time t.

When the speed is steady, the driving torque must be equal and opposite to the retarding torque, and then we have VI $cos\ \phi = k\frac{N}{t}$, *i.e.*, VI $cos\ \phi \times t = k$N, and therefore the energy consumed is proportional to the number of revolutions of the disc.

Consequently, if a train of wheels carrying dials is geared to the spindle upon which the disc rotates, the dials can be calibrated directly in kilowatt-hours.

There are two common types of watt-hour meter, viz. :—

i. *Induction motor meters*, which are identical in principle with induction wattmeters, the spring control being omitted. They are extensively used on A.C. systems.

ii. *Ironless motor meters*.—This type consists essentially of an ironless electric motor in which the field is energized by a current coil, and the armature by a voltage coil. The retarding torque is provided by the usual aluminium-disc eddy-current brake. The principle, therefore, is the same as that of the dynamometer type of wattmeter with an eddy-current brake substituted for the spring control.

The instrument is suitable for D.C. or A.C., but it is not so commonly met with as the mercury and induction types.

7. Ampere-hour meters.—Are suitable for D.C. only, and are of two main types :—

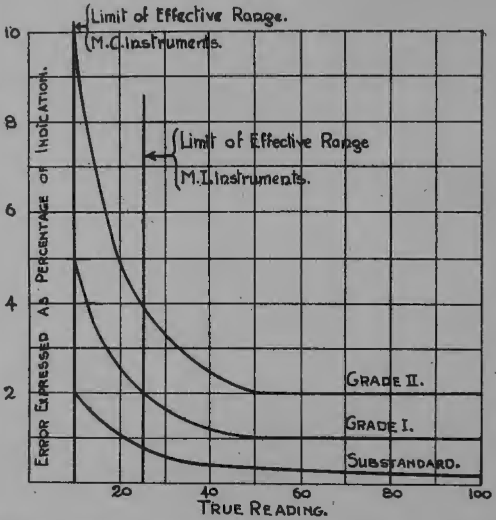
i. *Mercury motor meters*.—In this type a disc of copper, traversed radially by the current in the circuit, is submerged in a bath of mercury and rotates in a magnetic field provided by a permanent magnet.

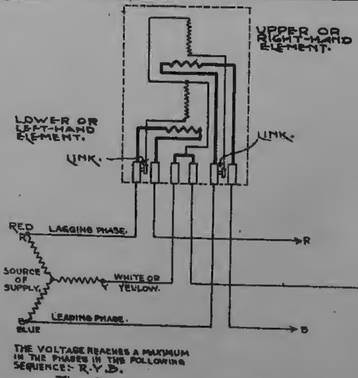
Mercury motor ampere-hour meters are largely used in house service work in preference to watt-hour meters because they are cheaper, and the energy loss in a voltage coil is avoided. The instruments are calibrated in Board of Trade units, at the declared voltage of the system, and therefore they register correctly at this one particular voltage only.

ii. *Electrolytic meters*.—These depend upon the well-known law that the total chemical effect of an electric current is proportional to the quantity of electricity that has passed. They possess the important advantages of cheapness and of being free from moving parts, and hence from mechanical friction. On the other hand,

LIMITS OF ERROR. VOLTMETERS *(See Section 15).*
(See B.S.S. 89)

Fig: 1.





THE VOLTAGE REACHES A MAXIMUM IN THE PHASES IN THE FOLLOWING SEQUENCE:- R.Y.B.

Fig: 2. STANDARD PHASE-ROTATION DIAGRAM. (for 3 phase meters) they are suitable for small installations only and require to be reset periodically.

8. Standards of accuracy.

i. *Indicating instruments.*—B.S. Specification No. 89 divides ammeters, voltmeters, and wattmeters into three categories, viz. :—

(*a*) Sub-standard.
(*b*) First grade.
(*c*) Second grade.

The supply of these instruments for W.D. purposes, however, is governed by G.D.E.S. No. 3, which does not permit the use of second-grade instruments.

For the exact requirements reference must be made to the two specifications referred to, but the following notes will give a general idea of the accuracy specified.

Effective range.—In ammeters and voltmeters, this is defined as starting at *one-tenth* the maximum scale value in the case of moving coil instruments, and at *one-quarter* of the same value in moving-iron and other square-law instruments.

The limits of accuracy prescribed for *single-range* instruments, from the maximum of the effective range down to *half* the maximum scale value, expressed as a *percentage of the indication*, may be summarized approximately as follows :—

—	*Sub-standard.* Per cent.	*First grade.* Per cent.	*Second grade.* Per cent.
Ammeter	±0·5	±2	±4
Voltmeter	±0·2	±1	±2
Wattmeter at unity P.F.	±0·5	±2·5	±5
Wattmeter from unity to 0·5 P.F.	±1·0	±4·0	±8

From half the maximum scale value down to the lower limit of the effective range, the error figures are one-half the above values, but they are expressed as a percentage of the maximum scale value. This will, perhaps, be made clear by reference to Pl. **24**, Fig. 1, in which the error allowed in voltmeters is plotted as a percentage of the indication throughout the effective range.

The errors allowed in multi-range instruments are larger, and in the case of ammeters the figures given above include the errors permissible due to the use of shunts, but not those due to the use of current transformers.

In a power-factor meter the maximum error allowed between 0·5 and unity factor, at ordinary frequency, or at the frequency marked on it, is ± 2 degrees of angle.

In a frequency meter the limit of error prescribed is 1 per cent. of the value of the reading at the middle point of the scale.

ii. *Recording instruments.*—B.S. Specification No. 90 for recording ammeters, voltmeters, and wattmeters gives figures for limits of error, expressed as a percentage of the maximum scale value, as follows :—

Ammeter	± 3 per cent.
Voltmeter	± 2 per cent.
Wattmeter at unity P.F. ..	± 3·5 per cent.
Wattmeter from unity to 0·5 P.F.	± 6·5 per cent.

iii. *Integrating instruments (Electricity supply meters).*—Meters, upon the readings of which charges to consumers of electrical energy are based, are legal instruments. They must comply as regards accuracy with the requirements of the Electricity Commissioners. At any point from one-tenth load to full load, the error must not exceed ± 3½ per cent. for meters in which the maximum current for full load does not exceed 3A, or ± 2½ per cent. for meters in which the full-load current is more than 3A.

B.S.S. No. 37 classifies meters in two grades. (*a*) Substandard. (*b*) Commercial. The limits of error specified are briefly as follows :—

(*a*) *Sub-standard* :	± 0·75 per cent., *or* + 1·5 per cent., *or* — 1·5 per cent.
(*b*) *Commercial :*	(from 10 per cent. to 125 per cent. of marked current).
A.C. Meters :	± 2·5 per cent. (2 per cent. if there are no external shunts or transformers).
D.C. Meters :	Below 10 amperes ± 2·5 per cent.
D.C. Meters :	10 amperes and over ± 2·0 per cent.

It will be seen that instruments complying with the B.S.S. also satisfy the legal requirements.

Meters should start and continue running steadily with a current equal to 0·5 per cent. of the marked current, and they should not register on the voltage coil alone even with 10 per cent. increase of voltage above the marked value.

All meters should be capable of withstanding considerable overloads for short periods ; up to 50 amperes rating, 100 per cent. overload for 30 minutes, and from 50 to 1,000 amperes rating, 50 per cent. overload for the same period. For further details the specification must be referred to.

The greatest care must be taken to connect up meters *exactly* according to makers' instruction diagrams sent with the instruments. This applies particularly to 3-phase instruments. Pl. **24**, Fig. 2, shows the standard connections for a two-element 3-phase meter.

Definition of percentage error.—The error of the meter is the difference between the amount registered and the true kilowatt-hours. This error is expressed as a percentage of the true kilowatt-hours. Thus a meter which registers 95 per cent. of the true kilowatt-hours is said to have an error of minus 5 per cent.

The percentage error of a meter can be determined as follows :—

(*a*) *From registration.*

$$\text{Per cent. error} = \frac{\mathrm{R}-\mathbf{kWh}}{\mathbf{kWh}} \times 100.$$

Where R = registration of meter in kilowatt-hours.
kWh = true kilowatt-hours passed through the meter.

(*b*) *From revolutions of rotor.*

$$\text{Per cent. error} = \frac{\mathrm{T}-t}{t} \times 100.$$

Where t = actual time (or time as observed) required for a given number of revolutions.
T = true time, or time a correct meter would take for a corresponding number of revolutions.

Example : A single-phase A.C. meter has a testing constant of 872·7 revolutions per kilowatt-hour. When the load is steady at 1,800 watts the disc makes 55 revolutions in two minutes. What is the percentage error ?

$$\textit{Meter registers } \frac{55}{872{\cdot}7} = 0{\cdot}0630\mathbf{kWh}.$$

$$\textit{True kWh} = 1{\cdot}8 \times \frac{2}{60} = 0{\cdot}060\mathbf{kWh}.$$

$$\therefore \text{ per cent. error} = \frac{0{\cdot}063 - 0{\cdot}060}{0{\cdot}060} = 5 \text{ per cent. } \textit{high}.$$

It is to be noted that a " *short time* " test of a meter ***in situ*** by means of stop-watch, voltmeter and ammeter (or wattmeter) cannot be considered as legal proof of the accuracy of the meter, although it is a simple and convenient means of ascertaining expeditiously whether or not it has a serious error. Even sub-standard testing instruments may have an error of 0·5 to 1·0 per cent., and there is a personal error in starting and stopping the watch. Moreover, the accuracy of the gearing is not verified if the revolutions of the disc only are checked. To get conclusive results a dial test over a considerable period must be made.

9. **Power losses in instruments.**—When measuring the input to incandescent lamps, fans, and other small apparatus, the power losses in the instruments themselves must be allowed for.

The following rough figures will give some idea of what these losses may amount to :—

i. *Permanent Magnet Moving Coil Instruments*—
 Ammeter : 7½ watts per 100 amperes.
 Voltmeter : 1–2 watts per 100 volts.

ii. *Moving iron instruments*—
 Ammeter : 2–3 watts (4–6 volt-amperes on A.C.) at full load.
 Voltmeter : 3–5 watts per 100 volts (with minimum of 4 watts for low-range instruments).

iii. *Dynamometer wattmeters*—
 Current coil : 2–3 watts (4–6 volt-amperes on A.C.) at full load.
 Voltage coil : 1–2 watts per 100 volts.

The volt-amperes taken by the M.I. voltmeter, and the voltage coil of the dynamometer wattmeter, are not appreciably greater than the watts.

It may be noted that the standard connections for a single-phase wattmeter are as in Fig. 1, with the volt coil on line side of the current coil, in which case the power loss in the current coil is registered by the instrument. With connections as in Fig. 2, the instrument registers the loss in the volt coil. As this latter loss is constant, the (2) connection is the most convenient when instrument losses are being allowed for.

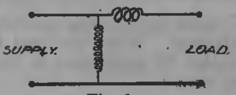


Fig. 1.

Fig. 2.

10. **Synchronizing gear.**—Before alternators can be connected in parallel it is necessary to ensure :—

i. Equality of voltage.
ii. Equality of frequency.
iii. Coincidence of phase.
iv. Same phase sequence (in the case of 3-phase machines).

(iv) is ensured on first installation, a simple form of phase-sequence indicator being a 3-phase induction motor. Subsequently it is sufficient to ensure (i), (ii), and (iii) on one phase only.

Ordinary incandescent lamps, suitably connected across the switch contacts, form the simplest indicators of (ii) and (iii). Equality of frequency is indicated by absence of flicker, and coincidence of phase by maximum brightness or total darkness according to whether the lamps are cross-connected or direct-connected across the switch contacts.

Lamps are not sufficiently sensitive, however, for modern requirements, and they do not show whether the incoming machine is too fast or too slow, but they are still met with as auxiliaries to the more exact instruments known as *synchroscopes*, which are now universally employed.

One type of *rotary synchroscope* is an adaptation of the power-factor meter described in para 4. The rotor of the instrument is similar to the moving element of the P.F. meter, and its windings are connected to the incoming machine. The stator is energized by a single-phase voltage winding, connected to the bus-bars. Before synchronism is reached, the rotor runs at a speed and in a direction which are determined by the difference in frequency between the bus-bar voltage and that of the incoming machine. When the frequencies are equal the instrument acts as a phase indicator, and at synchronism the pointer attached to the rotor remains stationary at the centre of the scale.

An auxiliary set of bus-bars, which are known as the *synchronizing bus-bars* and are in reality small insulated wires only, are usually provided, with plug connections on each alternator panel, so that one synchronizing panel may be sufficient for any number of machines (*see* Pl. 37).

It is advisable for the synchroscope to be in full view of the engine-driver as well as the switchboard attendant.

11. Instrument transformers. (B.S.S. No. 81.)—In A.C. systems above 500 volts or so, it is usual to connect all instruments, trip coils, etc., through small transformers specially designed for the purpose. The introduction of these "instrument" transformers, besides insulating the instruments from the H.V. system and so permitting them to be handled with safety, enables standard sizes to be used, whatever the primary (H.V.) current and voltage may be. The standard secondary values are 5 amperes and 110 volts, therefore on a 6,600-volt system a 6,600/110 voltage transformer is required, and for a maximum primary current of 100 amperes, a 100/5 current transformer is necessary. The instruments are scaled to read the primary values. Incidentally, as small wiring only is required between instruments and transformers, the latter can be placed in the main connections and the former in any convenient position on the switchboard. For this reason current transformers are often used on low-voltage boards as well.

The secondary winding of a current transformer should never be open-circuited while the primary is carrying an appreciable current, as the core may become saturated. This saturation affects the accuracy of the transformer, and the excessive iron losses may result in a rise of temperature sufficient to damage the windings.

Voltage transformers, being shunts on the system, must be connected through fuses. All instrument transformers must have one pole earthed on the secondary side to guard against the danger which would be incurred if the insulation were to break down between the primary and secondary windings.

The standard specification recognizes four classes of instrument transformers, viz. : Class A for laboratory work, classes B and C for ordinary switchboard instruments, and class D for relays, trip coils, etc. For classes B and C, the ratio error allowed is one per cent., and the phase errors 60 minutes and 120 minutes respectively for current transformers, and 30 minutes and 60 minutes respectively for voltage transformers. The volt-ampere rating is called the *rated burden.* The standard sizes of current transformers are 5, 15, and 40 volt-amperes, and for voltage transformers 15, 50, 100, and 200 volt-amperes for single-phase, and 25, 50, and 100 volt-amperes per phase for 3-phase transformers.

Examples of the connections of instrument transformers, trip coils, &c., are given in Pls. **35** and **36**, referred to in Sec. **17.**

It will be noted that on each panel the instruments, relays, and trip coils are connected to one set of current transformers and one 3-phase voltage transformer. Providing that the volt-ampere ratings of the transformers are adequate there is seldom any objection to this arrangement. The burdens may be estimated at 5VA for each instrument coil, 3VA for each relay coil, and 30–40VA for each direct-connected overload trip coil. On account of the high volt-amperes taken by the latter it is advisable to shunt these coils by fuses. This is, of course, common practice for another reason (*see* Sec. **13**, para. 6).

16. *Switchboards.*

1. Having described the most common types of switchgear and instruments likely to be met with, it remains to consider briefly their assembly on switchboards of various types.

All switchboards and their components must be constructed to comply with the following regulations and specifications :—

i. Home Office Electricity Regulations for Factories and Workshops.
ii. I.E.E. Regulations for the Electrical Equipment of Buildings.

iii. British Standard Specification No. 162 for "*Electric Power Switchboards.*" (This specification contains a complete list of the various British Standard Specifications affecting the components.)

iv. Such Government Departments and D.W. Electrical and other Specifications as may be applicable and available.

The main points to be aimed at in switchboard design are :—

i. Simplicity of arrangement, control, and operation.
ii. Accessibility for adjustments and repairs.
iii. Reliability.
iv. Safety from fire.
v. Safety of operating personnel.

All these points were kept in mind above when describing the switchboard components, but the following remarks may be added :—

The switchboard should be arranged in *panels* so that distinct and separate portions of the board are definitely allocated to each generator, feeder, &c. All generator panels should be grouped together, as should the feeder panels and so on.

It is advisable in small power stations to install the switchboard so that the generators controlled are in full view. If this is not possible some form of electrical communication must be provided, and this is especially necessary in A.C. generating stations. In the case of large generators it is usual to provide a servo-motor on the steam supply controlled by the switchboard attendant.

All switches, circuit breakers, regulators, etc., should be easy of access and measuring instruments so placed as to be easily read. Air break circuit breakers should be placed as high as possible and fuses (unless ironclad) as low as possible.

All connections should be made simply and symmetrically and the minimum amount of crossing should be aimed at.

All instruments and apparatus, the function of which are not at once obvious, should be clearly labelled.

Except for quite small low-voltage D.C. boards (up to 110 volts), for which varnished hard wood may be used, no combustible material should be used in the construction of switchboards.

Unless all parts are easily accessible from the front, ample room (say 3 feet) should be allowed behind switchboards.

2. Home Office Regulations.—Reference the safety of operators. The Home Office Regulations should be carefully studied in their entirety by all persons responsible for electrical installations.

A very important provision in these regulations makes it necessary for an *authorized person* (over 21 years of age) to be *in charge* of an electrical installation. This *authorized person* is legally liable with his employer for accidents which occur through neglecting to comply with the regulations, and ignorance is no excuse for non-compliance.

The regulations apply to all installations above 125V A.C. or 250V D.C.

The following are the principal regulations governing the design and equipment of switchboards :—

All conductors, switches, and apparatus to be efficient and suitable for the work to be performed, and to be so placed and safeguarded as to prevent danger to the operator.

When a conductor is permanently earthed, no circuit breaker, fuse, or other apparatus must be connected in such a way as to endanger the continuity of the earth connection.

Switchboards should be so arranged that—

(*a*) All parts which may have to be adjusted or handled are readily accessible.
(*b*) The course of every conductor can easily be traced.
(*c*) Conductors of different systems are kept well apart.
(*d*) All bare conductors are so placed or protected as to prevent danger from short circuit.

No bare conductors to be installed in accessible positions, unless the following clearances be allowed :—

Low voltage and medium voltage (*up to* 650 *volts*).	
Horizontal clearance	3 feet.
Clear height from the ground	7 feet.
High Voltage and Extra-High Voltage (*above* 650 *volts*).	
Horizontal clearance	3 feet 6 inches.
Clear height from ground	8 feet.

Bare conductors must not be exposed on both sides of passage ways, unless the clear width is 4 feet 6 inches for low voltage and medium voltage, and 8 feet for high voltage and extra-high voltage, unless conductors on one side are guarded.

No work must be carried on unless the circuit is dead. All cases of transformers, metal cases of instruments, metal handles of H.V. switches, &c., and all metal work other than the conductors to be efficiently earthed.

Adequate precautions to be taken to prevent *accidental* closing of a switch.

Adequate lighting to be provided.

Access to be possible to *authorized persons* only.

Instructions for treatment of persons suffering from electric shock to be affixed in all premises where electric energy is handled above low voltage.

400-VOLT, 3-PHASE, A.C. SWITCHBOARD. (E. and M. School S.M.E.)

PLATE 25.

[To face p. 78.

400-VOLT, 3-PHASE, A.C. SWITCHBOARD. (E. and M. School, S.M.E.)

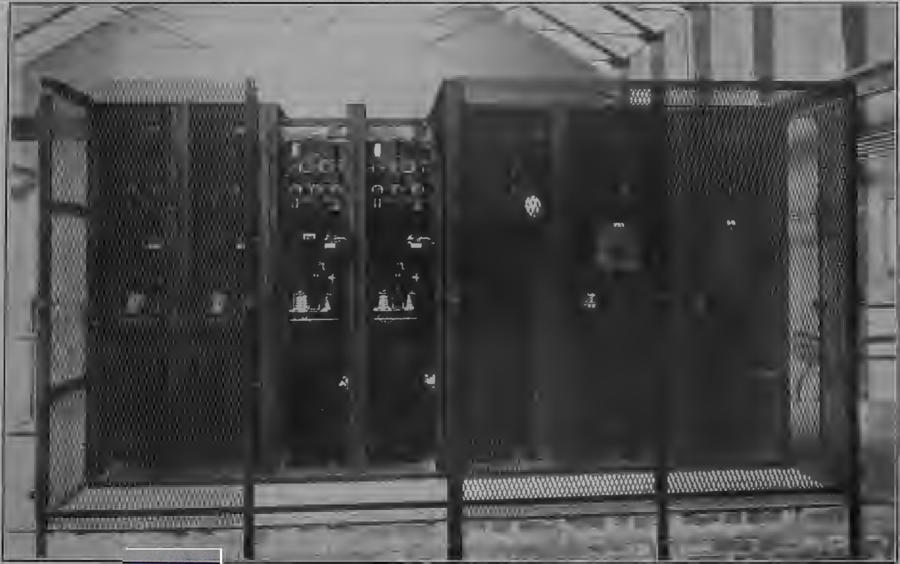


PLATE 26.

To face page 79.]

In connection with the last-mentioned regulation, the method that is recommended by The Royal Life Saving Society is given in Appendix IV.

3. Principal types of switchboard.—One or other of the following types will satisfy most service requirements :—

(*a*) *Low Voltage and Medium Voltage.*
  i. Flat back type.
  ii. Ironclad factory type.

(*b*) *High Voltage.*
  iii. Stationary fixed sheet steel cubicle type.
  iv. Draw out truck cubicle type.

(i.) *Open type, Flat back switchboards.*—This is the type universally used in L.V. and M.V. D.C. work, but it is also quite suitable for M.V. 3-phase A.C. If alterations and repairs on individual panel equipments are to be carried out without making the whole board dead, it is necessary to provide isolating switches on each panel and fireproof partitions between panels. Incidentally, the partitions tend to localize the effects of faults.

Pls. **25** and **26** show the 7-panel 400-volt 3-phase 4-wire A.C. switchboard in the Electrical School Power Station S.M.E., which consists of two 75kW generator panels, four feeder panels and one spare panel. The overall length of the board is 13 feet 9 inches, and depth 2 feet 6 inches. The switchboard platform is 24 feet by 10 feet. The platform is constructed of 4-inch by 2-inch standard channel filled in with 2-feet by 2-feet chequer plate. It is supported on two 9-inch walls 5 feet apart. The clearance of the channels from the floor level is 7 feet. The slate panels are situated 6½ inches behind the inner side of the front wall, which is, therefore, conveniently situated to take the cable terminating boxes.

The synchronizing panel is to the left of the board (*see* Pl. **25**), and contains two voltmeters, a synchroscope and a frequency meter. All the main panels are fitted with oil circuit breakers and energy meters. The generator panels are each equipped with A.C. ammeter, wattmeter and power-factor meter, D.C. ammeter and voltmeter for alternator field, D.P. field switch (with discharge resistance at back), exciter field rheostat (back of board), alternator field rheostat (fixed below platform). The circuit breaker is fitted with three overload trips and one shunt trip, the latter being operated by the reverse power relays (at bottom of panel).

No. 4 panel (S.M.E. substation feeder) is equipped with ammeter and wattmeter and three overload trips on the circuit breaker. Nos. 5 and 6 panels (rotary and rectifier substations feeders) are each equipped with ammeter, power-factor meter and two overload and one leakage trip on the circuit breaker. No. 7, the school lighting feeder, has three ammeters and three overload trips on the circuit breaker.

Pl. **26** shows the back of the board, with a portion of the sheet iron cover above the bus-bars, and one section of the X.P.M. sheeting enclosing the back passage removed, and the bus-bars, isolating switches, current transformers and circuit breakers can be clearly seen. Sheet iron partitions are provided between the panels.

Where the number of instruments and apparatus is large, slate is perhaps the best supporting material to use, but since the slate is not now relied upon for insulation, sheet steel will often be found quite as suitable, and is lighter and cheaper.

The open type flat back switchboard is the cheapest type, but it is not suitable for damp or dusty situations, nor for operation by unskilled persons. Totally enclosed boards should be used in these circumstances.

(ii.) *Ironclad factory type.*—For factory and workshop conditions, total enclosure of all apparatus and connections is usually imperative. Pls. **27** and **28** show two designs of 400-volt 3-phase switchboards, with interlocked ironclad switches and switch-fuses, constructed on the " expanding " principle, to which additional bus-bar chambers and switchgear can be added as required. It comes out cheaper, and shortens up the board, if switches and fuses are arranged above and below the bus-bars. It is important to remember, however, that the connections must be so made that switch blades are " dead " when the switches are open, and the same remark applies to fuses which are controlled by switches. The design does not lend itself to the addition of a large number of instruments, but anything more than an ammeter is seldom required.

Pl. **27** shows a 400-volt, 3-phase, 4-wire ironclad distribution board in the workshops S.M.E. The overall dimensions are 4 feet 6 inches long and 6 feet 7 inches high. The total maximum incoming load current is 150 amperes per phase, and the maximum individual currents in the five branches approximately 75, 75, 40, 25 and 25 amperes respectively. A three-pole, 200-ampere, interlocked ironclad switch-fuse is provided on the incoming side, and five 100-ampere Home Office Pattern ironclad fuses on the branch connections. The fuse carriers are of porcelain. A disconnecting link is provided in the neutral connection in each fuse box for uniformity, although necessary only on the lighting feeders. The power and lighting loads are on separate branch feeders, which is good practice. No supports are provided for the bus-bars, which are of copper strip, and they depend for their spacing upon the stiffness of the connecting cables which are rubber insulated. This is a weak point, and

PLATE 27.

400-VOLT, 3-PHASE, A.C. SWITCHBOARD. FACTORY TYPE.
(E. and M. School, S.M.E.)

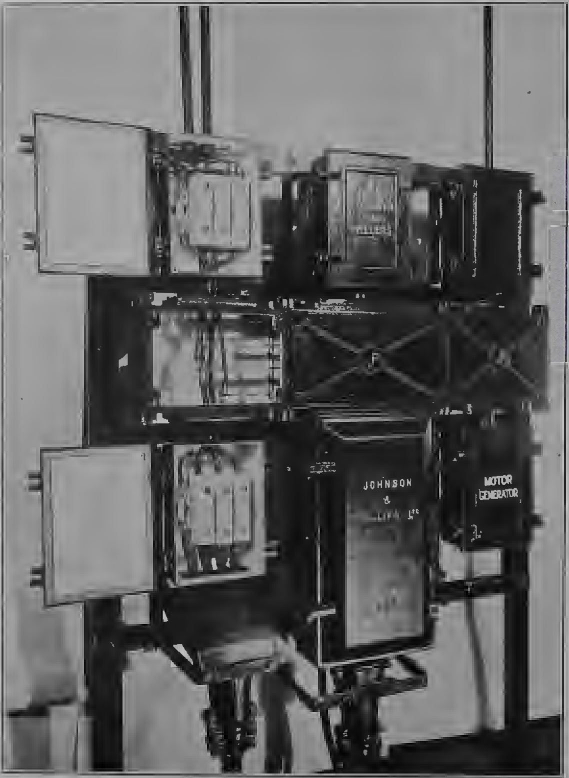


PLATE 28.

[*To face plate 27.*

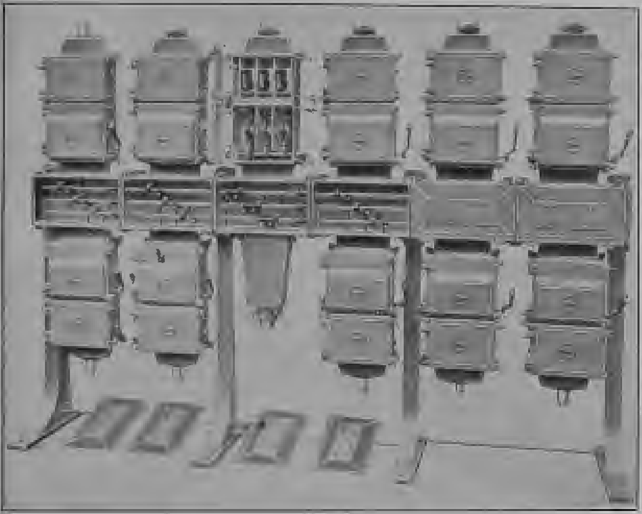


Fig. 1. [*Permission of Parmiter, Hope and Sugden.*

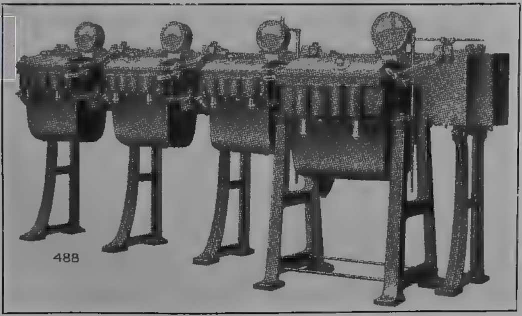
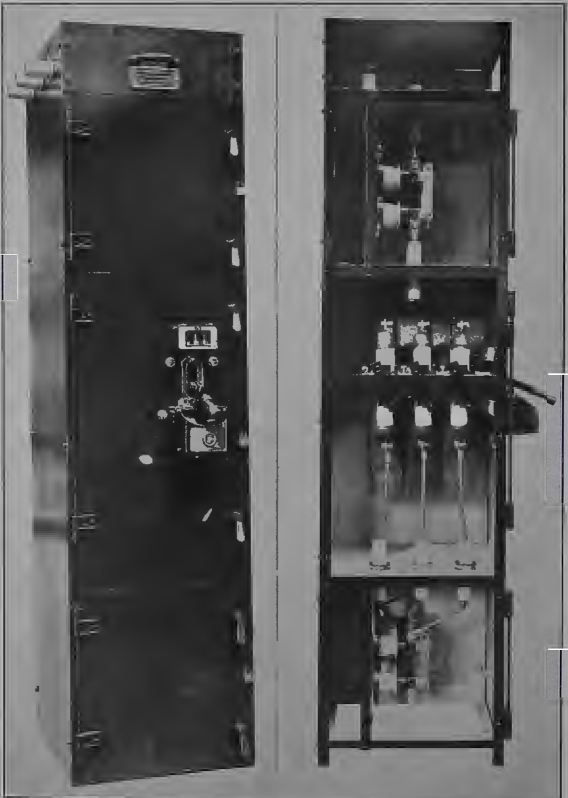


Fig. 2. [*Permission of George Ellison.*

FIXED STATIONARY CUBICLE.

Overall dimensions: 2′ 3″ wide, 2′ 3″ deep, 8′ 11″ high.
(Suitable for 11,000 Volts, 300 Amps. or 6,600 Volts, 600 Amps. 3-Phase.)



[*Permission of Ferguson, Pailin, Ltd., Manchester.*

unsupported bus-bars can only be permitted when the currents are relatively small.

This is the cheapest type of ironclad equipment procurable which complies with all regulations.

Pl. **28**, Fig. 1, shows a much superior (and naturally more costly) type, of larger capacity. The overall dimensions are 9 feet long by 7 feet high. The switch-fuses have a carrying capacity of 120 amperes each and the bus-bars are suitable for a maximum incoming load of 1,000 amperes per phase. The incoming supply is controlled by an oil circuit breaker (not shown). All the switchgear shown is interlocked so that it is impossible to open either the switch or the fuse lid until the corresponding switch handle has been placed in the " off " position. The bus-bars, and the bare copper connections from the bus-bars to the switches, are of round section throughout, and the clamps which are used for coupling the connections to the bus-bars are reamered out to the exact fit to the bars themselves, and this ensures a large surface of contact. The bus-bars are supported rigidly in mica-bushed metal clamps. The fuses are of special design giving a high rupturing capacity, a low working temperature and watt loss with a continuous carrying capacity of 90 per cent. of the fusing current. The fuse carriers are made of practically unbreakable moulded insulating material (similar to Bakelite), which is unaffected by any temperature likely to be experienced, and it is practically non-hygroscopic.

This type of switchboard is largely used in commercial work where the utmost reliability is essential.

In some cases, such as, for example, the control of a number of fairly large motors, which should be provided with discriminating overload protection, the arrangement shown in Pl. **28**, Fig. 2, may be used. A number of totally enclosed oil circuit breakers are supported on cast iron pedestals, and connected together by ironclad bus-bars, which is a very compact arrangement. This design is naturally more expensive than either of the two switch-fuse boards described above, but it is much cheaper than any other type of totally enclosed switchboard which would only be justified if a large number of instruments and auxiliary apparatus were required.

(iii.) *Stationary sheet steel cubicles.*—If the open type flat-back switchboard described above is provided with a sheet iron door at the back of each panel compartment, we have a number of sheet steel cubicles in which all live parts are totally enclosed, and the arrangement is quite suitable for 3-phase systems up to 11,000 volts.

Cubicles are generally constructed of sheet steel $\frac{1}{8}$ inch thick on an angle iron framework. They can be arranged for front access only, thus saving the space required for a passage way behind the board, but if space permits it is always an advantage to fit doors both back and front to facilitate the work of clearing and inspection. Cubicles should be so designed that any item of equipment can be removed without dismantling other apparatus. Pl. **29** shows a single non-interlocked cubicle with front access. Isolating switches are provided on both sides of the oil switch in separate and distinct compartments. No instruments are shown, but they can be fixed to the sheet doors as required. If desired fool-proof interlocking arrangements can be fitted to safeguard the operator in case he attempts an operation involving danger.

(iv.) *Draw-out truck type cubicles.*—In this type the complete equipment, including oil circuit breaker, instruments, &c., is mounted on a truck which can be withdrawn and handled with perfect safety. The truck carries contact jaws mounted on porcelain insulators which engage with contact blades mounted in the fixed portion of the structure. Continuity of supply can be maintained, if necessary, while overhauling any particular circuit equipment by inserting a truck from another circuit not required at the time. For generating stations and sub-stations of moderate capacity, this is the most compact form of switchgear to install, and its safety and reliability are unquestionable. It costs about 25 per cent. more than stationary cubicle switchgear.

Pl. **30**, Fig. 1, gives a side-view of a truck partly withdrawn with one side removed. Safety shutters are provided which automatically close over the fixed contact blades upon the withdrawal of the truck, and an interlocking arrangement also prevents the withdrawal or replacement of the truck while the circuit breaker is closed. Fig. 2 shows the assembly of five trucks similar to that illustrated in Fig. 1, and Pl. **31** gives the principal measurements of an equipment suitable for 6,600 volts, 600 amperes, or 11,000 volts, 300 amperes. This type of switchgear is not used on voltages above 11,000.

4. **Some other types of switchgear.**—The types described above should cover practically all military requirements, but the following may be referred to briefly :—

i. *Concrete cubicle type* (*B.S.S.* 268).—In this type all high-voltage connections, isolating switches, circuit breakers and instrument transformers are contained in concrete cubicles generally situated in a special room below, or at any rate apart from, the low-voltage control board, which is usually of the open flat back type and contains all the necessary instruments, relays, rheostats, &c. The circuit breaker is operated by remote electrical control. This design is often used for controlling large amounts of power and frequently each phase is housed in a separate cubicle.

PLATE 30.

TRUCK TYPE IRONCLAD SWITCHGEAR

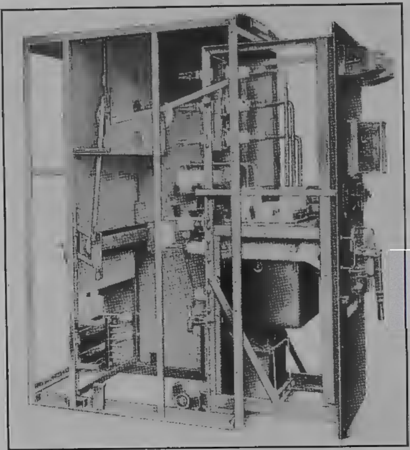


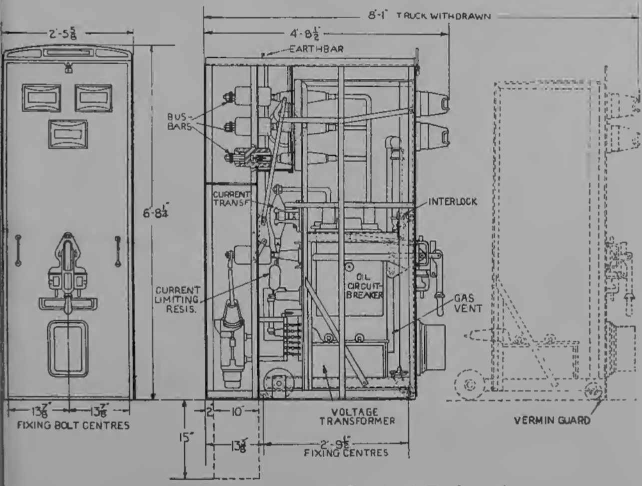
Fig. 1.—Typical 6,600 3-Phase T/B6 Equipment—Truck partially withdrawn, with Safety Shutters closed—one Side and Lower Intermediate Screen removed.

Fig. 2.—Typical T/B6 Switchboard.

[*Permission of The British Thomson-Houston Co., Ltd.*

TRUCK TYPE IRONCLAD SWITCHGEAR.

(Approximate Dimensioned Outlines.)



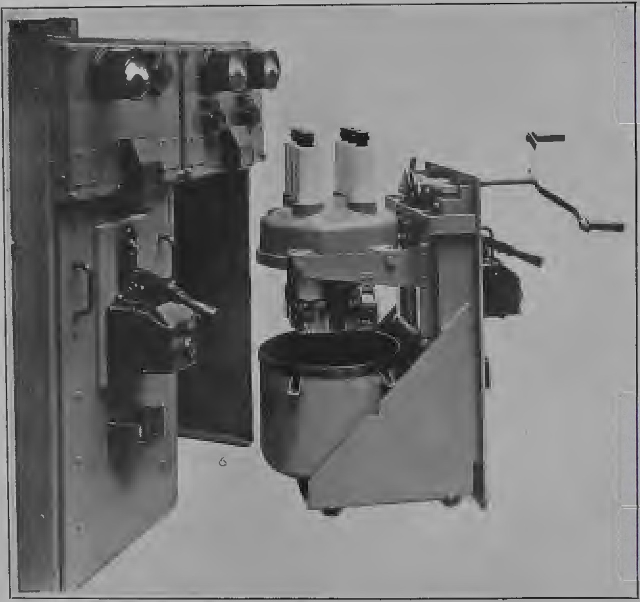
Typical Outline of a 3-Phase T/B6 Circuit Equipment.

(Equipments are Mounted at 2′ 6″ Centres.)

[*Permission of The British Thomson-Houston Co., Ltd.*

IRONCLAD COMPOUND FILLED SWITCHGEAR.

(Suitable for 3-Phase loads up to 11,000 Volts, 800 Amps.)



Overall dimensions of one unit: 4′ 3″ high × 1′ 9½″ wide × 2′ 7½″ deep (3′ 6″ including handle). Total depth with removable portion withdrawn: 5′ 6″. Additional height required to take a Voltage Transformer: 2′ 0″.

[*Permission of Ferguson, Pailin, Ltd., Manchester.*

ii. *Vertical draw-out gear.*—Where floor space is limited, ironclad switchgear can be obtained which provides for the withdrawal of the oil circuit breakers in a vertical plane. When arranged for upward isolation the isolating contacts may be oil-immersed, and this is sometimes an advantage.

iii. *Oil filled and compound filled gear.*—In all the above designs the main connections are air-insulated; but both horizontal and vertical draw-out types are manufactured in which the bus-bars, connections and instrument transformers are immersed in oil or compound. Such immersion has advantages in situations subject to extreme changes of temperature accompanied by excessive condensation and also for dealing with large amounts of power at very high voltages. Embedding the bus-bars in compound enables the design to be smaller and more compact, since the compound acts as a solid buffer against movement due to magnetic forces set up by heavy short-circuit currents. On the other hand, more copper must be used in the bus-bars and connections owing to the fact that the compound hinders the dissipation of heat. The instrument transformers should be immersed in oil, not compound, if they are to be conveniently accessible for overhaul.

These designs of compound filled switchgear are, however, rather expensive, and are seldom likely to be justified for dealing with the moderate amounts of power required for military purposes.

Pl. 32 shows one type of oil or compound filled switchgear suitable for direct hand or remote electrical control. Essentially each unit comprises two portions (i) The draw-out truck, and (ii) the housing.

A detachable handle operates a positive multi-toggle device for raising or lowering the circuit breaker on the truck, *i.e.*, vertical isolation is employed. Interlocks are provided to prevent moving the circuit breaker if it is closed, or if the truck is not secured to the top plate.

The housing comprises separate chambers for the bus-bars, the current transformers, and the cable box.

The instrument panel accommodates all instruments, circuit breaker auxiliary switches and auxiliary connectors for connecting small wiring from truck to housing. A special feature of this panel is its detachability as a whole, and the facility for access to the low tension terminals for inspection or test whilst the unit is in commission.

17. *Switchboard panel equipment.*

(*See* B.S.S. 194 for D.C. and 195 for A.C. Panel equipments.)

It is manifestly impossible to give the details of switchboard panels suitable for every purpose. This section, therefore, will be confined to diagrams of connections of a few typical panels, which can, by a slight rearrangement or by the addition of other instruments or apparatus, be adapted for particular requirements.

1. A **low-voltage D.C. 2-wire battery and booster panel** of the simplest form is shown in Pl. **33.**

The reverse current cut-out is shown again on Pl. **19,** and is described in Sec. **13.**

Two ampere-hour meters are necessary in order that the charge and discharge may be recorded independently. The instruments are fitted with stops to ensure that they register in one direction only. The booster field is excited from a potentiometer rheostat to enable the voltage to be reduced to zero if required. Alternatively to fuses and Crawley cutout, D.P. circuit breakers with overload and reverse current trips might be used. Fuses should be of the enclosed type and placed low down on the panel. All the switches shown are D.P., but the linking bars are omitted for clearness. The centre switch should be kept in the top position except when charging.

2. A **D.C. compound generator panel** is shown in Pl. **34.**

The three single-pole switches shown are linked together, and to ensure that it makes connection first, the upper contact of the equalizing switch is longer than those of the two other switches. The two circuit breakers are linked together, and are each fitted with an overload trip, but the negative pole only is fitted with a reverse current trip. It will be clear that a reverse current trip on the positive pole would be useless, since the equalizing connection prevents the reversal of direction of current in the series coil.

Particular attention is drawn to the fact that the ammeter and watt-hour meter must be connected in the negative main as shown. Strictly speaking, the only switchgear necessary is the D.P. circuit breaker and equalizing switch, providing that the latter is interlocked with the former.

A portable voltmeter, fitted with four plug contacts, is used for paralleling. Two of the plugs are connected together and the other two are joined to the instrument coil. The instrument normally reads the full bus-bar voltage on either side of a central zero, but a press switch is provided for

[To face p. 84.

PLATE. 33.

BATTERY AND BOOSTER PANEL.

(See Section 17.)

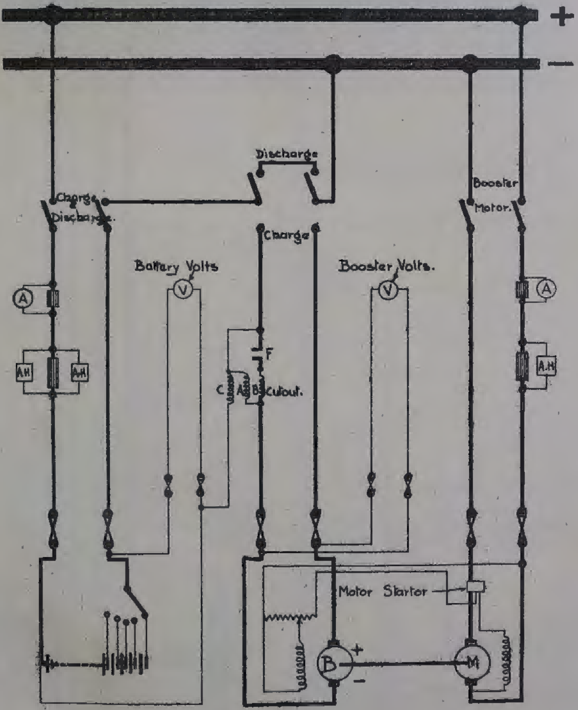
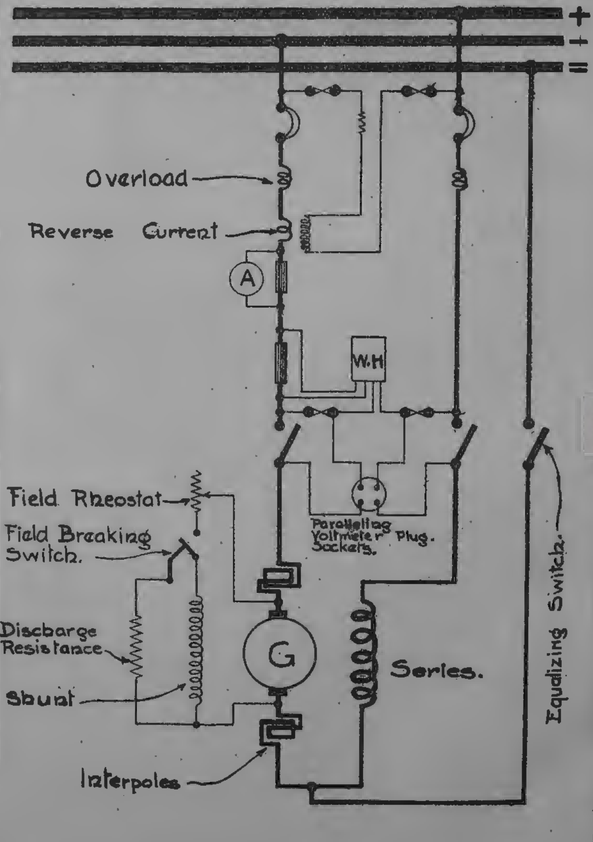


PLATE 34.

COMPOUND D.C. GENERATOR PANEL.

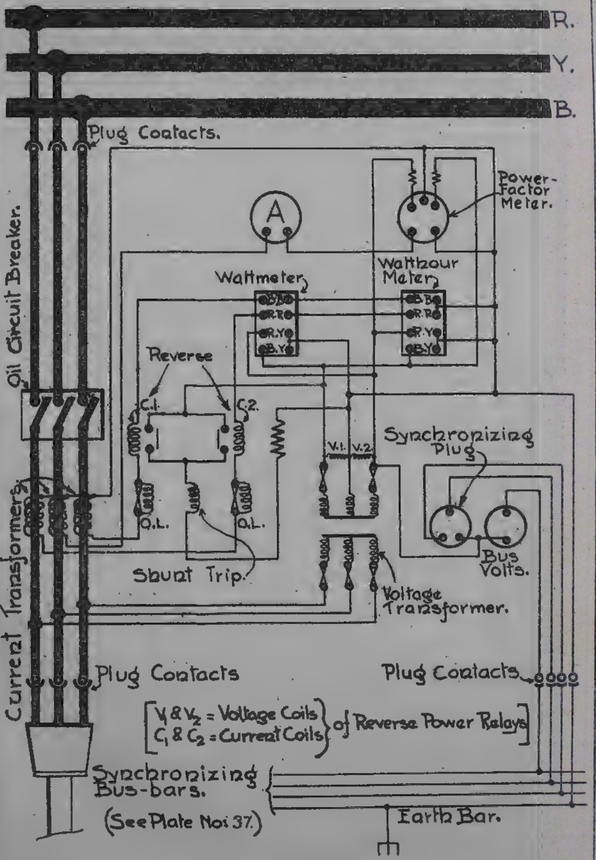
(See Section 17.)



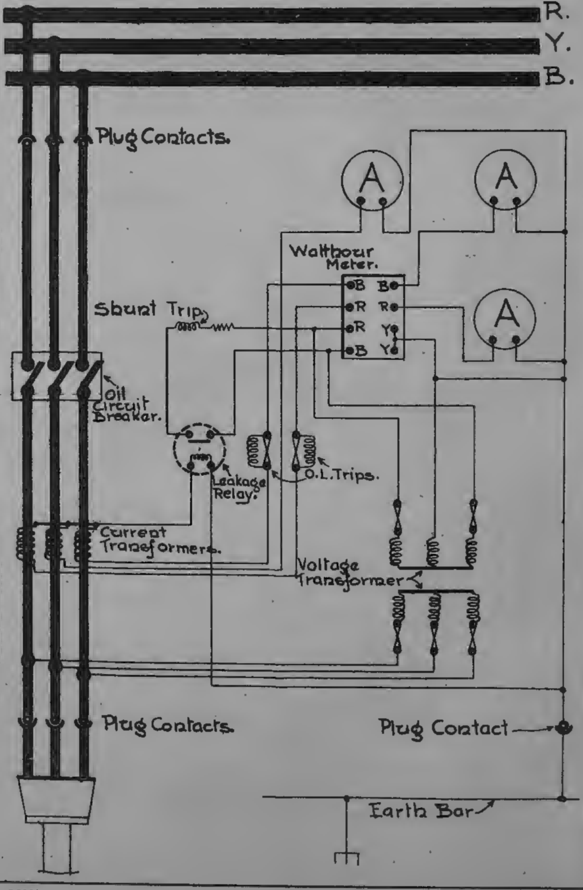
[To follow plate 34.

PLATE 35.

A.C. HIGH VOLTAGE, 3 PHASE, 3 WIRE, GENERATOR PANEL. (See Section 17.) IRONCLAD TRUCK TYPE.



A.C. HIGH VOLTAGE. 3PHASE. 3WIRE. FEEDER PANEL. (see Section 17.) IRONCLAD TRUCK TYPE.



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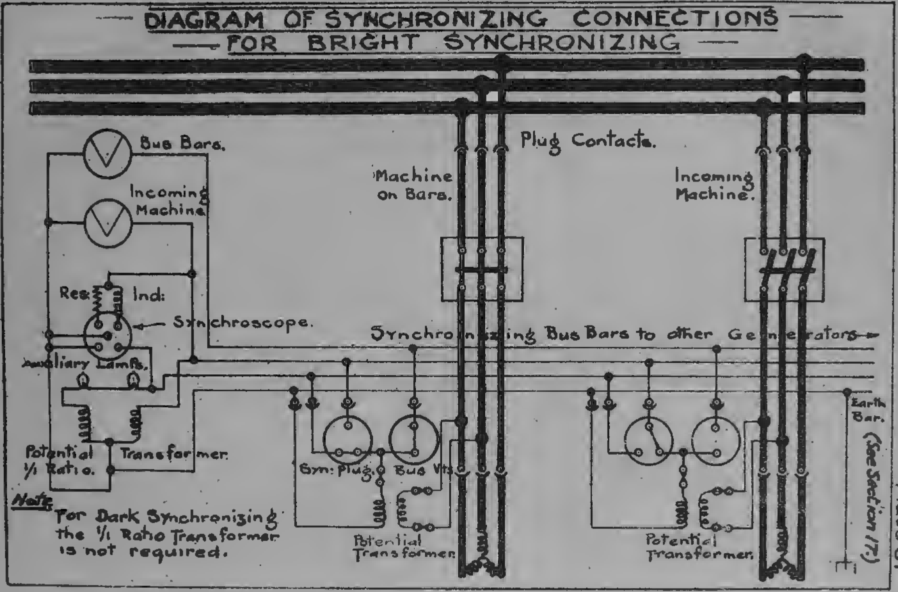


DIAGRAM OF SYNCHRONIZING CONNECTIONS FOR BRIGHT SYNCHRONIZING

Note. For Dark Synchronizing the 1/1 Ratio Transformer is not required.

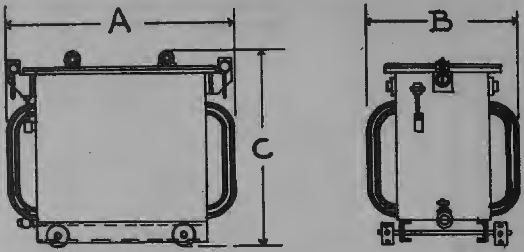
(See Section 17.)

Plate 37.

[To follow plate 36.

PLATE. 38

APPROXIMATE OVERALL DIMENSIONS AND WEIGHTS OF 3 PHASE, OIL COOLED, INDOOR TYPE TRANSFORMERS. (See Section 21)



Transformers above 75 K.V.A have external tubes for oil circulation.

SIZE. K.V.A.	A.	B.	C.	Weight in Cwts.			OIL GALS.
				Tank	Transf:	Oil.	
30	36"	25"	44"	4	5½	3¾	50
50	38"	26"	46"	4½	6¾	4	53
75	47"	30"	48"	5½	10	6¾	89
100	50"	32"	52"	7¾	12	7¼	95
120	54"	37"	54"	8¼	12½	7½	100
150	56"	40"	58"	8½	15	8	105
175	57"	41"	60"	10	18½	9½	127
200	58"	42"	62"	10¼	20	10½	140
250	64"	42"	64"	11½	23½	11½	152
300	67"	47"	65"	12¾	26¾	12½	166
400	72"	48"	68"	16	30	14¼	188
500	72"	50"	69"	17¾	32	15½	205

Permission of THE BRUSH ELECTRICAL ENG: CO: LTD.

altering the scale to 5—0—5 when the machine and bus-bar volts are nearly equal.

3. **An A.C. high-voltage, 3-phase, 3-wire generator panel** of the truck type is shown in Pl. **35.**

Overload and reverse power protection are provided, the former with fuse shunted trip coils to give a time lag. The terminals of the voltage coils of the wattmeter and watt-hour meter are shown together to minimize crossing of connections. The current and voltage coils of the reverse power relays are shown apart for the same reason. An ammeter switch is sometimes fitted to enable the current in each phase to be measured independently when required. All the apparatus shown is fixed to the movable truck.

4. **An A.C. high-voltage, 3-phase, 3-wire feeder panel** of the truck type is shown in Pl. **36.**

Overload and leakage protection are provided. As an alternative to the three ammeters shown, a single instrument would suffice if an ammeter switch were fitted. The terminals of the voltage coils of the watt-hour meter are shown together to minimize crossing of connections. All apparatus shown is fixed to the movable truck.

In addition to the three circuit contacts which, when the truck is pushed home, make on to the fixed bus-bar contacts, there is also a substantial earth contact which connects the truck framework to a fixed earth-bar.

It may be noted that the circuit diagrams shown in Pls. **35** and **36** are suitable for any type of 3-phase, 3-wire switchboard, but isolating switches are essential on fixed types of switchboard in place of the plug contacts.

On M.V. switchboards the voltage transformers are not required.

5. A **synchronizing panel** is shown on Pl. **37.**

A synchroscope and lamps are both shown, but the latter may be regarded merely as stand-by.

This panel would, as a rule, be on a projecting bracket at the end of the switchboard so that the attendant can see it from the generator panel without moving.

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Electrical Measuring Instruments. D. J. Bolton. 12*s*. 6*d*.

Commercial A.C. Measurements. G. W. Stubbings. 15*s*.

British Standard Specifications. 2*s*. each :—

37. Electricity Meters.
81. Instrument Transformers.

89. Indicating Instruments.
90. Graphic (or Recording) Instruments.
162. Electric Power Switchboards.

D.W. Standard Specifications for E. and M. Services :—
No. 4. Switchboards for Low and Medium Voltage.
No. 10. Metal-Clad Switchgear for Low and Medium Voltages.

Government Department Electrical Specifications :—
No. 3. Indicating Instruments.
No. 6. Switches with Fuses (up to 250 volts.)

CHAPTER III.

TRANSMISSION AND CONVERSION.

18. *Principles.*

1. Unless purely military considerations dictate otherwise, it may now be considered axiomatic that electrical energy should be taken from local supply systems wherever practicable, to avoid the installation of small and inefficient generating stations. It will, of course, be necessary in all cases to consider carefully the economics of the problem. The cost of the transmission line may be prohibitive if the amount of power required is small and the distance relatively large, and it is obviously essential to compare the initial and running costs of the two solutions.

The elementary principles of H.V. transmission will now be dealt with. Three-phase A.C. is practically the only system in use at the present day, although single-phase may sometimes be found convenient on short branch lines for lighting loads.

2. **Classification of voltages.**—In the E.C. Regulations the word "voltage" means the difference of electrical potential between two conductors or between a conductor and earth. The various regulations to be complied with for securing the safety of life and property and the reliability of the supply depend upon the working voltage. ·Voltages are classified as follows :—

i. Low voltage : 0–250 volts.
ii. Medium voltage : 250–650 volts.
iii. High voltage : 650–3,000 volts.
iv. Extra high voltage : above 3,000 volts.

3. **British Standard High Voltages.**—The following values are now established as British Standard High Voltages :—

At the *generator terminals* or the terminals of step-up transformers : 3,300V, 6,600V.

Transmission voltages : 3,300V, 6,600V, 11,000V, 22,000V, &c., in multiples of 11,000V for higher voltages.

Receiving voltages at the primaries of step-down transformers : 3,000V, 6,000V, 10,000V, &c.

Many non-standard systems are still in use, but every endeavour is being made in Great Britain to avoid extensions to such systems and to convert them to standard-voltage systems as early as possible.

It may be mentioned that 11,000V is the highest voltage at which it is usual to generate directly in alternators of moderate capacity. At higher voltages appreciable brush discharge occurs, which destroys the insulating material by the formation of ozone. If higher line voltages are used, step-up transformers will generally be necessary. It may be added, however, that alternators of very large capacity (50,000kVA and above) are now being developed, which generate directly at 33,000 volts.

It will be noted that the figures allow for a 10-per-cent. drop in the transmission line. This will frequently be too much to allow for good regulation, but it is not intended that the standard voltages should be rigidly adhered to, and, in fact, 10-per-cent. variation is provided for by manufacture in their standard designs.

4. **British Standard Frequency.**—Except for special purposes, such as traction, for which a frequency of 25 is approved, 50 is now the established British Standard Frequency for general purposes.

A large number of other frequencies are still in use in other parts of the world, and about 20 per cent. of the power stations in Great Britain are still using non-standard frequencies, mainly 25 or 40. Most of them will no doubt be converted to 50 in the near future.

5. **Overhead lines versus underground cables.**—It is now generally agreed that cross-country transmission and rural distribution can be effected much more cheaply by overhead lines than by underground cables.

For military purposes, particularly under war conditions, where an extensive use of pole transformers can be made and where requirements change suddenly and often, the cost of installing and maintaining a cable system would be probably more than three times as great as that of an overhead system, and even with this enhanced cost the cable system would not be so adaptable to alterations and additions. Cable may have to be resorted to for tactical reasons, but in these days of high-explosive shells it will generally be impracticable to bury the cable at the depth which would be necessary to secure immunity from damage, and it will probably be found that the most suitable transmission is overhead, with supports camouflaged and liberal use made of line stays to localize the effects of a shell.

It is essential to go underground in the neighbourhood of aerodromes, and it is advisable to do so in the actual residential portions of permanent camps and barrack areas, but under active service conditions the chances of accidents are seldom sufficient to warrant cable, except in short lengths when leading in to buildings.

Although a well-laid underground transmission line under peace-time conditions is supposed to be immune from breakdown, this ideal is not attainable in practice. Faults on overhead lines are a little more frequent than on underground lines, but whereas a fault on the former can be rectified in from a few minutes to a few hours, cable faults may require several days to locate and repair.

6. The advantages and disadvantages of overhead lines in comparison with underground cables may be summarized as follows :—

Advantages.

i. First cost considerably less than that of cable.
ii. Much easier and cheaper to inspect and repair.
iii. Much easier to make branch connections.
iv. Line can often be constructed from the local resources of the country if porcelain insulators are available.
v. Transformers can be installed on poles, and the cost of providing buildings is thereby avoided.
vi. If subsequent extensions make it necessary, the line can be adapted for a higher voltage simply by changing the insulators.
vii. Since the line current can be raised to a high figure before being limited by heating considerations, very large additions of load can be carried in emergencies (with, of course, increased line-voltage drop). Such overloading is not possible with cables.
viii. Shortest route usually practicable.

Disadvantages.

i. Wayleaves sometimes difficult to obtain.
ii. More subject to atmospheric disturbances.
iii. More liable to faults due to kites, birds, and malicious damage.
iv. More liable to damage from enemy action.
v. A certain element of danger to life and property, which is, however, negligible in a properly constructed line.

In practice the advantages far outweigh the disadvantages.

7. Cables are dealt with in Chapter V and overhead lines in Chapter VI.

19. *Line calculations.*

1. Most consuming devices, other than those in which electrical energy is converted directly into heat, possess appreciable inductance, the effect of which is to cause the current to lag behind the voltage. Capacitance has the

opposite effect, but in the calculations in this section a lagging current only will be considered.

Cables, in themselves, possess inductance and capacitance, both of which may be considered negligible for the purpose under consideration; but overhead lines, although their capacitance may be neglected, have considerable inductance, and this has an important effect upon the pressure drop.

2. The inductance of two parallel conductors is approximately equal to $(0{\cdot}842 \log \frac{S}{r} + 0{\cdot}0914\mu)$ **mH** per **1,000** yards, where S is the distance between centres of conductors and r is the radius of each conductor, both expressed in the same units; μ is the permeability of the conductor material and is equal to unity for all conductors except iron and steel. The insertion of μ in the formula simply serves as a reminder that, if iron conductors are used, the second term may become very large, but, as μ is some function of the current and the frequency, no exact value can be given to it, except the value of unity for non-magnetic conductors.

The figure 0·0914 assumes uniform current distribution, and is not quite correct for all sizes of conductors owing to the *skin effect*, but, since the quantity is always relatively small for non-magnetic conductors in practical transmission lines, it may be assumed to be constant.

For a single conductor $L = (0{\cdot}421 \log \frac{S}{r} + 0{\cdot}0457)$ **mH** per 1,000 yards.

3. If R, X, and Z represent the total resistance, reactance $(2\pi f L)$, and impedance of a line respectively,

then the impedance drop $= ZI = \sqrt{R^2 + X^2} \times I$ volts.

With D.C. the drop would have been RI only.

The values of R, X, and Z for some common sizes of copper and aluminium conductors are given in Tables **A** and **B.**

For full details of all British Standard Sizes reference must be made to B.S.S. 125 for H.D. Copper, and 215 for H.D. Aluminium conductors.

The line impedance drop is not generally in phase with the line voltages V_1 and V_2 at the generating and receiving ends of the line respectively. Unless the line has appreciable capacitance *$V_1 - V_2$ is less than ZI*, not equal to it, as might be supposed from the formula $V_1 - V_2 = RI$ in D.C. work. But if $V_1 - V_2$ is limited to 10 per cent. of V_2 no great error is introduced by assuming $V_1 - V_2 = ZI$ for conductors up to 0·1 sq. in. When greater accuracy is required, the formula $V_1 - V_2 = RI \cos \phi + XI \sin \phi$ should be used. This formula is obtained as follows.

TABLE A.—*Particulars of hard drawn copper conductors.*

Strands and diameter.	Nominal standard section. Sq. inch.	Approx. overall diameter. In.	Standard resistance (R) per 1,000 yds. at 60° F. Ohms.	Reactance (X) per 1,000 yds. 50 ~. 3-ft. spacing. Ohms.	Impedance (Z) per 1,000 yds. 50 ~. 3-ft. spacing. Ohms.	Breaking Load. Lb.	Standard weight per 1,000 yds. Lb.
1/0·136	0·01453	0·136	1·699	0·38	1·74	912	168·0
1/0·147	0·01697	0·147	1·454	0·37	1·50	1,056	196·2
1/0·162	0·02061	0·162	1·197	0·37	1·25	1,266	238·3
1/0·178	0·025	0·178	0·9909	0·36	1·06	1,515	287·7
1/0·193	0·02926	0·193	0·8425	0·36	0·91	1,749	338·3
3/0·104	0·025	0·224	0·9987	0·35	1·06	1,418	300·6
3/0·147	0·05	0·317	0·4943	0·33	0·59	2,914	600·5
3/0·18	0·075	0·388	0·3294	0·32	0·46	4,250	900·3
7/0·136	0·100	0·408	0·2469	0·31	0·40	5,870	1,196·0
7/0·152	0·125	0·456	0·1976	0·31	0·37	7,232	1,494·0
7/0·166	0·15	0·498	0·1656	0·30	0·34	8,530	1,782·0
7/0·18	0·175	0·540	0·1408	0·30	0·33	9,918	2,095·0
7/0·193	0·200	0·579	0·1224	0·29	0·32	11,270	2,408·0
7/0·204	0·225	0·612	0·1096	0·29	0·31	12,510	2,691·0
7/0·215	0·25	0·645	0·09861	0·29	0·31	13,790	2,989·0

TABLE B.—*Particulars of hard drawn aluminium and steel cored aluminium conductors.*

Strands and diameter. Aluminium.	Strands and diameter. Steel.	Aluminium section. Sq. inch.	Equiv. copper section. Sq. inch.	Approx. overall diameter. In.	Standard resistance (R) per 1,000 yds. at 60° F. Ohms.	Reactance (X) per 1,000 yds. 50 ~. 3-ft. spacing. Ohms.	Impedance (Z) per 1,000 yds. 50 ~. 3-ft. spacing. Ohms.	Breaking Load. Lb.	Standard weight per 1,000 yds. Lb.
3/0·118	—	0·0322	0·02	0·254	1·238	0·34	1·28	859	117·7
3/0·132	—	0·0402	0·025	0·284	0·9869	0·33	1·04	996	147·3
7/0·122	—	0·0804	0·05	0·366	0·4942	0·32	0·59	2,042	292·8
7/0·149	—	0·1200	0·075	0·447	0·3310	0·31	0·45	2,929	436·8
7/0·173	—	0·1618	0·10	0·519	0·2453	0·30	0·39	3,791	588·8
7/0·193	—	0·2013	0·125	0·579	0·1970	0·29	0·35	4,620	732·8
7/0·211	—	0·2407	0·15	0·633	0·1647	0 29	0·33	5,404	875·9
19/0·149	—	0·3251	0·20	0·745	0·1222	0·28	0·31	7,786	1,188·0
6/0·0935	1/0·0935	0·0404	0·025	0·28	0·9865	0·33	1·04	2,181	217·8
6/0·132	1/0·132	0·0805	0·05	0·40	0·4935	0·32	0·59	4,106	434·2
6/0·161	1/0·161	0·1197	0·075	0·48	0·3315	0·30	0·45	5,874	645·9
6/0·186	7/0·0623	0·1598	0·10	0·56	0·2482	0·30	0·39	7,387	804·2
6/0·208	7/0·0693	0·1999	0·125	0·62	0·1984	0·29	0·35	9,134	1,005·0
30/0·102	7/0·102	0·2403	0·15	0·71	0·1656	0·28	0·33	15,238	1,473·0
30/0·118	7/0·118	0·3216	0·20	0·83	0·1238	0·27	0·31	20,394	1,971·0

The vector diagram Fig. 3 illustrates the various voltages in a simple transmission line.

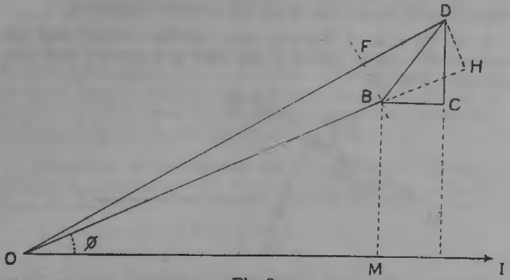


Fig. 3.

OI = current vector (vector of reference).
cos ϕ = P.F. at load (lagging).
OD = V_1 = line voltage at generator.
OB = V_2 = load voltage.
BC (parallel to OI) = RI = resistance drop in line.
DC (at right angles to OI) = XI = reactance drop in line.
BD = ZI = impedance line drop.
OM = watt component of load voltage.
BM = wattless component of load voltage.
FD = OD − OB = $V_1 - V_2$ = true difference between voltage at generator and voltage at load.

$$\frac{\text{FD}}{\text{OB}} \times 100 = \frac{V_1 - V_2}{V_2} \times 100 = \text{percentage regulation of}$$

line (if FD = value at full load).

The triangle BCD is much exaggerated in the figure, since in practice BD does not usually exceed 10 per cent. of OB.

Although the various quantities could be obtained from a large-scale figure, it is better in practice to use an analytical formula deduced from the geometry of the vector diagram.

If DH be drawn at right angles to OB produced, then BH will be approximately equal to FD.

$\therefore$ BH = $V_1 - V_2$.

But BH = BC $\cos\phi$ + DC $\sin\phi$
= RI $\cos\phi$ + XI $\sin\phi$,

i.e., difference of voltage between generator and load = RI $\cos\phi$ + XI $\sin\phi$.

(If the current leads on the voltage, ϕ must be taken as a negative angle, in which case the

$$\text{VD} = \text{RI}\cos\phi - \text{XI}\sin\phi.)$$

4. The total voltage drop in single-phase lines

$$= 2R_1I \cos\phi + 2X_1I \sin\phi,$$

where R_1 and X_1 are the values for a single conductor.

5. In the case of 3-phase lines, the line current and voltage are 30° out of phase if the load is balanced and non-inductive (Fig. 4).

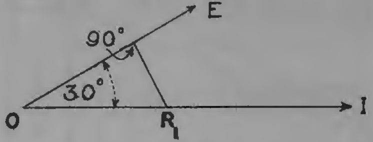


Fig. 4.

Therefore, the component of the resistance drop in phase with the voltage $= IR_1 \cos 30°$ for each line, *i.e.*, $2IR_1 \cos 30°$, or $\sqrt{3}R_1I$, between lines. Similarly, the reactance drop is $\sqrt{3}X_1I$, if the three conductors are symmetrically placed at the corners of an equilateral triangle.

Generally, when the load is balanced, the difference between line voltage at generator and line voltage at load in 3-phase lines $= \sqrt{3}R_1I \cos\phi + \sqrt{3}X_1I \sin\phi$.

6. **Choice of working voltage.**—The best working voltage to be adopted in a new scheme will depend upon the amount of power to be transmitted and the distance.

If the cost of conductors only is considered, the working voltage should be made as high as possible, since, for equal line loss, the weight of copper required will vary inversely as the square of the voltage employed; but it must not be overlooked that the higher the voltage the greater will be the cost of cables, switchgear and transformers.

Where extensive use is made of overhead lines, the overall cost of the line is not much affected by the value of the working voltage, and, when once committed to H.V., it is not wise to select a voltage lower than 6,000V. A useful working rule is to allow 1,000V per mile, and then to select the nearest standard voltage.

7. **Most economical conductor.**—Space will permit of little more than passing reference to Kelvin's important law of economy which states that—*The most economical cross-section of a conductor is that which makes the annual cost of the* I^2R *losses equal to the annual interest on the capital cost of the conductor plus the necessary annual allowance for depreciation.*

It will be noted that this law takes no account of the length of the line, the transmission voltage, the voltage drop, temperature rise, or the size and mechanical strength of conductors. Further, in practice, no definite value can be assigned to I unless the annual load curve can be predicted with reasonable accuracy.

In cases where the weight of copper involved is considerable and reliable data is available the law is very useful as a check, but for military purposes the size of conductor is invariably decided upon by the voltage regulation permissible, and Kelvin's law is rarely helpful.

8. **Example of calculation for simple H.V. feeder.**—Calculation can usually be commenced with the following known data :—

i. Magnitude and P.F. of load.
ii. Distance in miles.
iii. Percentage drop to be allowed at full load.
iv. Material of conductor.
v. Spacing of conductors.

First, assume a voltage of 1,000V per mile. Since there are two unknowns, X and R, in the formula $V_1 - V_2 = RI \cos\phi + XI \sin\phi$, a rough value of one of them must be assumed in the first place. A reference to Table A will show that for copper conductors with 3-feet spacing the value of X can be taken without serious error as 0·34 Ω per 1,000 yards of single conductor to enable a formula to be used to get a first approximation to R. Having determined R in this way, the tables should be consulted and the next larger standard conductor selected. This size of conductor will generally be suitable, but, if the drop comes out too great, a size larger should be selected and the calculation repeated.

The conductor resistance at 60° F. will be taken in calculations here and throughout the book, and this is usually quite near enough in Great Britain. In tropical climates and hot situations generally, the increase of resistance due to temperature should be borne in mind.

9. For example, suppose that a load of 200kW at 0·8 P.F. is to be transmitted 5 miles by an overhead line with copper conductors, that the spacing of the conductors is 3 feet and that the line voltage drop at full load is not to exceed 5 per cent.

i. *Single phase.*—Unless the supply voltage is fixed, assume 1,000 volts per mile; the nearest standard delivery voltage is then 6,000.

$$I = \frac{W}{V \cos\phi} = \frac{200{,}000}{6{,}000 \times 0{\cdot}8} = \frac{125}{3} \text{ amps.}$$

Taking $X = 0{\cdot}34\ \Omega$ per 1,000 yards, and inserting known values in the formula

$$V_1 - V_2 = 2(R_1 I\ cos\ \phi + X_1 I\ sin\ \phi)$$

we get $300 = 2 \times \frac{125}{3} (R_1 \times 0{\cdot}8 + 0{\cdot}34 \times 5 \times 1{\cdot}76 \times 0{\cdot}6)$

whence $R_1 = 2{\cdot}26\ \Omega$ total per single conductor

$$= \frac{2{\cdot}26}{5 \times 1{\cdot}76} = 0{\cdot}257\ \Omega \text{ per 1,000 yards.}$$

From Table **A** the next larger size of standard conductor is 7/0·136 (0·1 sq. in.), for which $R = 0{\cdot}2469\ \Omega$ and $X = 0{\cdot}31\ \Omega$ per 1,000 yards.

Using this conductor the voltage drop will be

$$2(R_1 I\ cos\ \phi + X_1 I\ sin\ \phi)$$

$$= 2 \times 5 \times 1{\cdot}76 \times \frac{125}{3} (0{\cdot}2469 \times 0{\cdot}8 + 0{\cdot}31 \times 0{\cdot}6) = 281 \text{ volts.}$$

$$\therefore \%\ \text{Voltage regulation} = \frac{281 \times 100}{6{,}000} = 4{\cdot}7\ \%.$$

The power loss at full load

$$= 2I^2R_1 = 2 \times \left(\frac{125}{3}\right)^2 \times 0{\cdot}2469 \times 5 \times 1{\cdot}76 = 7{,}550 \text{ watts.}$$

$\therefore$ % *Line Power Loss at full load*

$$= \frac{7{,}550 \times 100}{200{,}000} = 3{\cdot}775\ \%.$$

ii. *Three-phase.*—

$$I = \frac{200{,}000}{\sqrt{3} \times 6{,}000 \times 0{\cdot}8} = \frac{125}{3\sqrt{3}} \text{ amps.}$$

$$VD = \sqrt{3}\,(R_1 I\ cos\ \phi + X_1 I\ sin\ \phi) = 300 \text{ volts.}$$

$$= \sqrt{3} \times \frac{125}{3\sqrt{3}} (0{\cdot}8\ R_1 + 0{\cdot}6 \times 0{\cdot}34 \times 5 \times 1{\cdot}76)$$

whence $R = 6{\cdot}75\ \Omega$ total per single conductor

$$= \frac{6{\cdot}75}{5 \times 1{\cdot}76} = 0{\cdot}767\ \Omega \text{ per 1,000 yards.}$$

From Table **A** the next larger size of standard conductor is 3/0·147 (0·05 sq. in.), for which $R = 0{\cdot}4943\ \Omega$ and $X = 0{\cdot}33\ \Omega$ per 1,000 yards.

This size is really a good deal larger than necessary, but it is the nearest primary standard stranded conductor. If it is necessary to cut things fine, a secondary standard stranded conductor could be selected from B.S.S. 125. There is also a primary standard solid conductor, 0·204 inch diameter (0·03269 sq. in.), which has a resistance of 0·754 Ω per 1,000 yards, but solid conductors larger than 0·193 inch diameter are not recommended.

0·193 is rather too small for the present purpose, but we will work out the voltage drop for this size of conductor as well as for 3/0·147.

(*a*) *Using* 3/0·147.—

$$\text{VD} = \sqrt{3} \times 5 \times 1{\cdot}76 \times \frac{125}{3\sqrt{3}} (0{\cdot}4943 \times 0{\cdot}8 + 0{\cdot}33 \times 0{\cdot}6).$$
$$= 218 \text{ volts.}$$

$$\therefore \% \text{ Voltage regulation} = \frac{218 \times 100}{6{,}000} = 3{\cdot}63\ \%.$$

Line power loss at full load $= 3\text{I}^2\text{R}_1$

$$= 3 \times \left(\frac{125}{3\sqrt{3}}\right)^2 \times 0{\cdot}4943 \times 5 \times 1{\cdot}76 = 7{,}550 \text{ watts.}$$

$$\therefore \% \textit{ Power loss at full load} = \frac{7{,}550 \times 100}{200{,}000} = 3{\cdot}775\ \%.$$

(*b*) *Using* 0·193.—

$$\text{VD} = \sqrt{3} \times 5 \times 1{\cdot}76 \times \frac{125}{3\sqrt{3}} (0{\cdot}8425 \times 0{\cdot}8 + 0{\cdot}36 \times 0{\cdot}6)$$
$$= 326 \text{ volts.}$$

$$\therefore \% \textit{ Voltage regulation} = \frac{326 \times 100}{6{,}000} = 5{\cdot}43\ \%.$$

Line power loss at full load $= 3\text{I}^2\text{R}_1$

$$= 3 \times \left(\frac{125}{3\sqrt{3}}\right)^2 \times 0{\cdot}8425 \times 5 \times 1{\cdot}76 = 12{,}900 \text{ watts.}$$

$$\therefore \% \textit{ Line power loss at full load} = \frac{12{,}900 \times 100}{200{,}000} = 6{\cdot}45\ \%.$$

Economy Check.—With a common form of military load curve having a load factor of 20 per cent., the value of I, which, if constant throughout the year, would produce the same heating loss as the actual variable load current produces per annum, may be taken for estimating purposes as 25 per cent. of the maximum load current.

On this assumption, the annual line losses are, using 3/0·147,

$$= 7{,}550 \times \left(\frac{25}{100}\right)^2 \times \frac{8{,}760}{1{,}000} = 4{,}130 \textbf{kWh}$$

and with energy at 2d. per unit.

$$\textit{Annual cost of heating losses} = \frac{4{,}130 \times 2}{240} = £34{\cdot}4.$$

Weight of 3/0·147 per 1,000 yards = 600 lb.

$$\therefore \textit{ Total weight of copper} = \frac{600 \times 5 \times 1{\cdot}76 \times 3}{2{,}240} = 7{\cdot}07 \text{ tons.}$$

Assuming cost of copper to be £100 per ton, and the annual interest and depreciation charge to be 7 per cent. per annum, then the ***annual charges on cost of conductors***

$$= \frac{7{\cdot}07 \times 100 \times 7}{100} = £49{\cdot}5$$

The above calculations have been repeated for 0·193-inch conductor and for *all* the primary and secondary *standard conductors* between 0·193 and 3/0·147, and the results are given in the following table :—

Size of conductor.	Line drop at full load.		Line power loss at full load.		Annual cost of line losses. £	Annual interest and depreciation charges. £	Total annual cost. £
	V	Per cent.	W	Per cent.			
1/0·193	326	5·43	12,900	6·45	58·8	27·9	86·7
1/0·204	300	5·00	11,600	5·80	52·9	31·2	84·1
7/0·08	287	4·95	11,000	5·50	50·1	34·1	84·2
1/0·215	254	4·23	10,400	5·20	47·5	34·7	82·2
7/0·092	235	3·92	8,300	4·15	37·9	45·1	83·0
3/0·147	218	3·63	7,550	3·77	34·4	49·5	83·9

It will be observed that the application of Kelvin's Law involves a good many assumptions, and, therefore, the maximum theoretical economy cannot be assured unless there is ample reliable data to work on. In our example there is no standard conductor available to enable the law to be complied with exactly, but 0·215 gives the greatest economy (theoretically). Over the whole range considered, however, the difference in annual overall costs is small, and it may be repeated that, for the light lines required for military purposes it is seldom worth while bothering about Kelvin's Law.

Bearing in mind the possibility of extensions and the desirability of using primary standard stranded conductors, 3/0·147 is undoubtedly the best size to choose from electrical considerations, if the line is a permanent one. In temporary lines 1/0·193 would probably meet the case. As will be seen in Chapter VI, mechanical considerations may also affect the choice.

A little consideration will show that 6,000 volts is the best standard voltage to employ. If 3,000 volts is chosen, a conductor will be required of four times the section, and consequently four times the annual interest and depreciation charges, to give the same percentage voltage regulation, whereas the annual line heating losses remain the same.

Moreover, nothing would be gained by selecting 10,000 volts, since the size of the conductor cannot be reduced below 0·162 by E.C. Regulations, and other complications in the shape of step-up transformers, &c., may have to be introduced.

10. **H.V. distribution.**—The above investigation deals with a simple H.V. feeder without branches, but a military system will more often take the form of a distributor fed at one end. In such a case the question of voltage regulation is not quite so simple.

Even when the generating station is more or less at the centre of gravity of the system, it will usually be found that each H.V. feeder has a number of tappings *en route*.

Every endeavour should be made so to design the system that the regulation necessary with change of load can be made at the switchboard in the generating station.

To fix the ideas the case of three transformers stations, A, B, and C, situated at load centres 5 miles apart, will be considered. Obviously, the best position for the generating station is at B, as shown in Fig. 5.

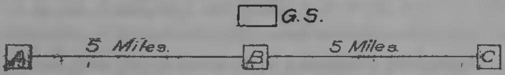


Fig. 5.

BA and BC are in this case simple H.V. feeders. It is not, however, always possible to place the station at the centre of gravity of the system, so the state of affairs when it is at A (Fig. 6) will be considered in detail.

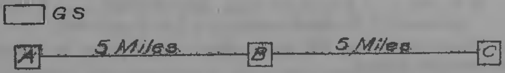


Fig. 6.

The inherent regulation of the various parts of the system will be assumed to have the following values :—

H.V. line 10 per cent., transformers 2 per cent., L.V. distribution 5 per cent., all values being for full load.

A generator voltage of 6,600V will be taken, which can be increased by hand regulation to 6,930V ; the declared voltage on lamps will be taken as 230V.

The transformers will be assumed to be wound to give 235V at their secondary terminals on open circuit and 230V at full load, and use will be made of a 2½ per cent. tapping at B and a 5 per cent. tapping at C.

Based on these assumptions the following table shows the voltage at the upper and lower limits of full load and no load, which might be expected at various points on the system :—

—	No load.		Full load.	
	V	Per cent. variation.	V	Per cent. variation.
Volts at bus-bars in generating station	6,600		6,930	
H.V. volts at A	6,600		6,930	
L.V. volts at transformer terminals A	235		241	
Lamp volts, load A ..	235	2+	230–241	0 to 5+
H.V. ,, ,, B ..	6,600		6,600	
L.V. ,, ,, B ..	240		236	
Lamp ,, ,, B ..	240	4½+	224–236	2½ — to 2½+
H.V. ,, ,, C ..	6,600		6,270	
L.V. ,, ,, C ..	246		230	
Lamp ,, ,, C ..	246	7+	218–230	5 — to 0

The no-load voltage can be improved by reducing the bus-bar volts, but the full-load voltages cannot be brought within the legal limit of 4 per cent.

The voltage regulation in this system would do perfectly well for power or temporary lighting, but in permanent H.V. distribution schemes with mixed loads it is advisable to limit the *total* regulation to from 8 to 12 per cent., which might be distributed somewhat as follows :—

H.V. line . . . 4 to 6 per cent., transformers . . . 2 to 3 per cent., L.V. distribution . . . 2 to 3 per cent.

When estimating full loads, due account must be taken of diversity factors.

11. It is inadvisable to use transformer tappings for more than 5 per cent. increase of voltage, since the **kVA** capacity is reduced in proportion to the amount of copper in use. This does not, of course, preclude the use of 10 per cent. tappings in special cases.

When once the lay-out of the system is decided, the transformer tapping connections are made once for all, and, were it not for the question of interchangeability, each sub-station could be provided with transformers wound for the particular transformation ratio suitable to its position in the system.

20. Automatic voltage regulators.—It will be clear from the above example that, to keep the voltage variation on consumer's premises within the statutory ± 4 per cent., the voltage drop in the various parts of the system must be kept low, even when the generation and distribution are under the same authority.

If a H.V. supply is taken in bulk from a separate authority the legal tolerance is + 12½ per cent. on the declared minimum voltage. That is, a tolerance of ± 6·25 per cent. is permitted at the H.V. supply terminals, but ± 4 per cent. only, at the consumer's lamp terminals. In such circumstances *Voltage Regulators* are essential, quite apart from any drop in the distribution which may also have to be compensated for.

In special cases of long feeders, whether H.V. or L.V., it may also be economical to provide voltage regulators to keep down the weight of copper.

One form of voltage regulator, called an "*Induction Regulator*," is constructed like an induction motor, but instead of the rotor being allowed to rotate as usual, provision is made for setting it in any angular position (about its axis) with regard to the stator. The stator windings are joined in shunt and the rotor windings in series with the line, and the transformer action, which varies with the setting of the rotor, can be used either to give a positive or negative voltage boost as desired.

Voltage regulation can also be obtained by transformer tappings, either on the main or an auxiliary transformer, the change from one tapping to another being made by drum type or contactor type switches.

Voltage regulators may be hand-controlled or *fully automatic*. The automatic feature is provided by means of a servo-motor controlled by one or more relays, set to operate by a predetermined variation in voltage or current, or both.

21. *Power transformers.*

1. **Weights and dimensions.**—The shipping weights (including packing-case) of oil-cooled transformers (50 periods) for installation indoors may be taken as 1 cwt. per **kVA** for **1kVA** transformers and ½ cwt. per **kVA** for 100**kVA** transformers.

The case dimensions are somewhat as follows :—

1kVA	12 in. × 10 in. × 16 in. high.
100**kVA**	50 in. × 30 in. × 50 in. high.

Allow on the average 1½ gallons of oil per **kVA** up to 50**kVA** and 1 gallon per **kVA** for larger sizes.

Particulars of a series of 3-phase transformers are given on Pl. **38.**

2. **Transport.**—It is usually desirable to transport transformers complete in their tanks, filled with oil, but with porcelain terminals removed to avoid breakage. This

minimizes erection work, and generally obviates drying out on site and also the necessity for a repetition of the H.V. insulation test, which is not often convenient to carry out at stations.

3. **Unpacking and storing.**—Transformers should be unpacked immediately they arrive at their destination. If they cannot be put into commission at once, transformers and oil must be stored in a dry place. *Special precautions must be taken to exclude moist air when transformers are stored without oil.*

4. **Installation.**—Transformers should be so located that the heat generated by the losses is properly dissipated. Ample space should be left around transformers for the passage of air heated by contact with the transformer tanks, and free entry from and escape of air to the atmosphere should be facilitated.

5. **Drying out.**—If a transformer arrives with its oil in a separate container, both windings and oil should be carefully dried before the H.V. voltage is applied to the windings. The drying should be carried out whether the insulation resistance appears good or not. The windings may be dried out as follows :—

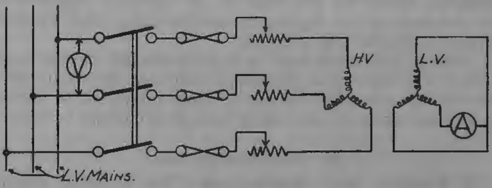


Fig. 7.

Connect the H.V. windings through an adjustable resistance to the L.V. supply, and short-circuit the L.V. windings (as in Fig. 7) through an ammeter reading up to 25 per cent. above normal full-load current of the transformer. The transformer should be run preferably out of its case to allow of good ventilation, and the temperature, as measured by a thermometer applied to the surface of the windings, must not exceed 80° C. at any part. This temperature should be maintained for several hours until the insulation resistance as measured by a 500V megger or other similar instrument, reaches a high figure. It should be remembered that the paper insulation has a negative temperature coefficient, and that, therefore, the insulation when cold is much greater than when hot; however, the transformer may have to work at 80° C. When the drying out is done in air, the current should not much exceed half full-load current for the first hour or so, but it may then be increased slightly if the temperature stops rising before 80° C. is reached. A larger current will clearly be necessary in cold weather than in hot. As high a voltage as may be available at the station (preferably not less than twice normal voltage) should then be applied between H.V. and L.V. windings, and between H.V. windings and core.

The oil may be dried as follows. First get rid of any water that may have settled out. Then place the oil in a suitable receptacle (the transformer tank will do) and heat it up to 105° C. by means of a resistance coil. The resistance wire should be of such a cross-section that its temperature is not sufficiently high to damage the oil by burning. If the oil is maintained at this temperature for several hours, it will usually be suitable for use, but moisture, even in quantities as small as one part in ten thousand, may have the effect of halving the pressure at which it breaks down; consequently it will be wise to apply the anhydrous copper sulphate test for moisture to ensure that the drying has been carried far enough. (Anhydrous copper sulphate is a whitish powder which indicates the slightest trace of water by turning blue.)

It should be noted that there is a slight fire risk.

6. **Notes on transformer oil.**—It might be well to point out that transformer oil has two functions beside that of cooling, viz., it increases the dielectric strength of the insulating material, and prevents the formation of ozone due to brush discharge. A thin highly-refined mineral oil is used and should be specially procured for the purpose. It should comply with B.S. Specification No. 148. The principal figures are :—

i.—The flash point must not be less than 145° C.

ii.—The loss by evaporation, when heated for 5 hours at 100° C., must not exceed 1·6 per cent.

iii.—The deposit of sludge, when heated at 150° C. for 45 hours in the presence of copper, must not exceed 0·1 per cent.

iv.—The viscosity, as tested by a Redwood viscometer, must not be more than 200 seconds at **15·5°** C.

v.—The *electric strength* of the oil, *i.e.* the voltage required to puncture a gap of 4 mm. long between two metal balls 13 mm. diameter, submerged in a vessel of specified dimensions, shall not be less than 30,000 volts.

On no account should ordinary lubricating oil be used, even as a temporary measure.

It should be noted that the alternate expansion and contraction of the oil, which occur owing to changes of load, cause air to be sucked into and expelled from the transformer tank.

Sludge is deposited from heated oil when in contact with air, and, further, the air is always more or less charged with moisture, which condenses inside the tank if the transformer cools quickly. These effects are negligible with small lighting transformers which are always excited and are not overloaded excessively, but they may necessitate special precautions being taken with large power transformers which are switched in and out morning and evening. Special devices can be fitted to transformers to reduce these effects to a minimum; one such device consists of a small expansion tank fitted above the main transformer tank which ensures that the latter is always filled with oil, and another consists of a hollow steel float made airtight by means of a leather gasket round the edge.

7. Inspection.—Periodical inspection of all transformers should be made about once every twelve months. The principal points to be looked for are shrinkage of windings, slackening of core clamping bolts, moisture and sludge in the oil, and deterioration of insulation due to excessive heating. Providing a transformer is not overloaded excessively, serious defects are unlikely to occur, and good quality oil will remain serviceable for an indefinite period. If a large amount of sludge is found, the oil should be renewed.

8. Capacity to install.—When deciding upon the size of transformer to install, due regard must be paid to the diversity factor (*see* Sec. **6**) and to the fact that 25 per cent. overload is possible for two hours. The diversity factor on a military lighting system is probably about 1·25. Therefore, **80kVA** of transformer capacity should be ample for **100kW** of installed lighting load. Pumping and isolated machine tools require **1kVA** per H.P. of motor capacity, but in large workshops the diversity factor may be 2 or more. Two cases of military workshops may be cited, one in which **30kVA** was ample for an aggregate of 75 H.P. and the other in which 450 H.P. of motor capacity was supplied by **150kVA** of transformer capacity. In the latter case, if it had not been for the poor power factor (sometimes as low as 0·6), a **100kVA** transformer would have been quite big enough.

9. 3-phase transformer connections.—The transformation of a 3-phase system from one voltage to another may be accomplished by means of one 3-phase or by two or three single-phase transformers. It should be particularly noted that transformers are very reliable forms of electrical apparatus. In a large station where some 150 transformers were installed of capacities varying from 5 to 150**kVA**, only 5 cases of breakdown occurred in 5 years, one due to overload, one to faulty manufacture, and three to abnormal voltage rises on the system, in spite of the fact that many of the transformers were frequently overloaded in excess of 25 per cent. for several hours.

As a general rule, it is bad practice to install three single-phase transformers instead of one 3-phase, where a 3-phase concentrated supply is required. 3-phase transformers are cheaper, lighter, rather more efficient, take up much less room (and, therefore, require cheaper transformer cabins), are simpler to connect up (there being only 3 H.V. outlets instead of 6), and, owing to the interlinking of the magnetic circuits, they deal with out-of-balance loads with less voltage variation than do three separate single-phase transformers. To deal with the remote contingency of a transformer burning out, a few spare transformers should be kept in a central store, say 5 per cent. of the aggregate installed capacity. These spares will also serve as substitutes for transformers under periodical overhaul.

It must not be inferred from the foregoing remarks that 3-phase transformers are always to be preferred for camp lighting, pure and simple. With 3-phase H.V. overhead distribution, single-phase transformers of small capacity are often preferable, on account of the simpler L.V. wiring and the simple type of pole-transformer installation which can be employed. In exceptional circumstances where there are perhaps only one or two fairly large transformer sub-stations with little likelihood of extensions, it may be wise to install three single-phase transformers in each sub-station with one single-phase transformer as a spare. The case for single-phase transformers in these circumstances would be stronger if the spare one were dispensed with and full advantage taken of the fact that, if one breaks down, the two remaining, connected in " V," will carry a load equal to 58 per cent. of the original capacity for an indefinite period, and 72 per cent., *i.e.*, 25 per cent. overload, for at least 2 hours ; this would generally be sufficient for the lighting peaks in military camps.

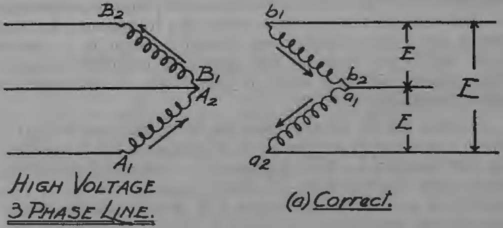
Whether 3-phase or three single-phase transformers are used, both H.V. and L.V. windings may be connected in star or delta.

Fig. 8 shows the connections that are possible :—

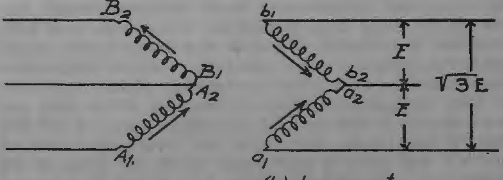
H.V.	L.V.	H.V.	L.V.
	Delta △		Delta △
Star ⅄	Star ⅄	Delta △	Star ⅄
	Inter connected Star or Zigzag		Inter-connected Star or Zigzag

Fig. 8.

Also two single-phase transformers will give a true 3-phase supply when connected in " V " (*see* Fig. 9).



(a) Correct.



(b) Incorrect.

Fig. 9.

Care must be taken to connect as shown in Fig. 9 (*a*). With reverse connection, as shown in Fig. 9 (*b*), the voltage between one pair of wires would be $\sqrt{3}$E.

From a first cost point of view the star winding is preferable, especially on the H.V. side, for the following reason :—

i. Voltage to earth is only $\frac{1}{\sqrt{3}}$ the voltage with delta connection, if neutral is earthed.

ii. Number of turns is $\frac{1}{\sqrt{3}}$ that of delta connection.

iii. Conductors are larger and, therefore, stronger and cheaper.

For a purely 3-phase power load either star or delta connections may be used, but for 3-phase 4-wire lighting distribution one of the following arrangements must be adopted if excessive out-of-balance voltages are to be avoided (*see* Fig. 10) :—

i. H.V. Delta—L.V. Star.
ii. H.V. Star (with neutrals of generator and transformer connected)—L.V. Star.
iii. H.V. Star—L.V. Interconnected Star.

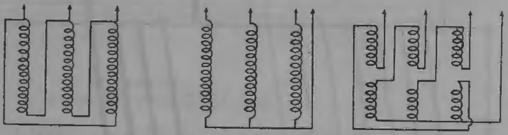

Delta. Star. Interconnected star.

Fig. 10.

10. **Parallel running of 3-phase transformers.**—When two or more transformers are connected on the H.V. side to the same H.V. feeder but supply separate L.V. networks, the connections are immaterial; but 3-phase transformers, if properly selected and connected, will run successfully in parallel on both H.V. and L.V. sides, even if of widely different capacities. When generators are run in parallel, a certain amount of compensation for slight differences in the internal characteristics of the machines can be obtained by hand regulation, but such regulation is not possible with transformers. The following conditions are necessary at *all* loads to secure proportionate loading :—

i. Equal impedance drop.
ii. Equal ratio of reactance to resistance.
iii. Equal transformation ratio.

Unless the transformers are identical in design and manufacture, it will usually be found that the load is not shared equally, a transformer with a poor regulation taking less than its proper share of the load. This means that the collective capacity of a bank of transformers of different inherent regulations will be less than the sum of their individual capacities.

When 3-phase transformers are connected in parallel on the H.V. and L.V. sides, they must be so connected that the following conditions are complied with :—

i. The polarity of corresponding phase windings must be the same.

ii. The grouping of the phase windings must be regular.

The H.V. windings are usually marked with the capital letters A, B, and C, and the L.V. windings with the small letters *a*, *b*, and *c*. The ends are differentiated by the subscripts 1 and 2, the direction of the E.M.F. being from 1 to 2, at the same instant in both windings.

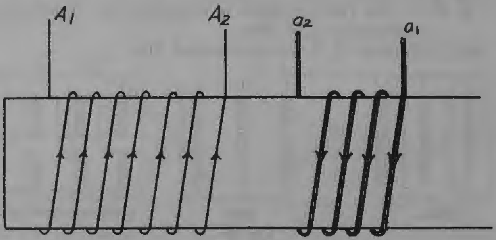


Fig. 11.

Fig. 11 shows the direction of the E.M.Fs. at the same instant on one limb of a 3-phase transformer. The windings are shown apart for clearness, but in actual transformers they are superimposed.

In modern transformers of the same manufacture all connections are arranged symmetrically, and clear diagrams are provided; therefore, no difficulty should be experienced in connecting up in parallel correctly. The following explanation will be of assistance in cases where transformers of different design are required to work in parallel.

First, to check the marking :—Dealing with each limb in turn, connect the two windings in series by connecting a_1 to A_2 (Fig. 11), and apply an alternating E.M.F. to the free ends a_2 and A_1. If the marking is correct, the E.M.F. measured between the H.V. terminals A_1 and A_2 will be less than the applied voltage.

Next, to check the relative polarity of the two transformers it is intended to work in parallel :—Assuming one transformer to be in service, connect up the other on the H.V. side. Then connect one L.V. terminal to its bus-bar (a piece of small fuse wire between the switch contacts will do), and connect a voltmeter between the other two pairs of switch contacts in turn. The following are typical results :—

V is the L.V. bus-bar voltage.

Example i.—Polarities reversed (Fig. 12).

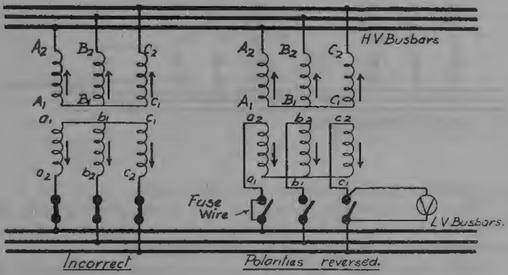


Fig. 12.

Voltmeter will read 2V in each case.

Example ii.—2-phase windings crossed (Fig. 13).

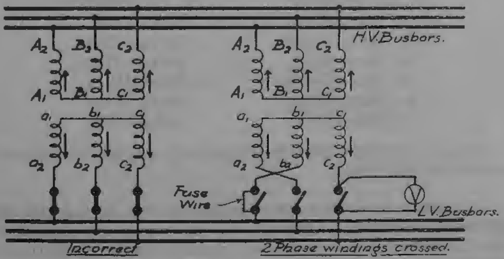


Fig. 13.

With connections as shown the voltmeter reads V volts. When connected across " B " phase switch it would read 2V volts. The cross-connections may be inside the transformer, but are more likely to be in the external connections between the transformer and the bus-bars.

Example iii.—Connections correct (Fig. 14).

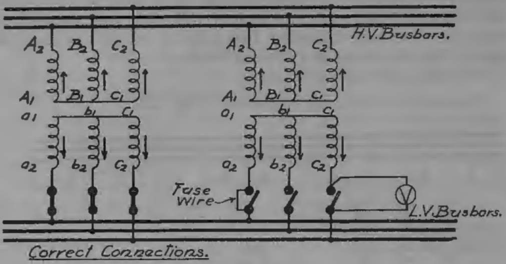


Fig. 14.

Voltmeter reading in each case will be zero.

The case where the polarity of one phase winding only is reversed can usually be determined by examination of the connections and will not be further considered.

Mesh connections will be found to present no difficulty if reasoned out as above.

ii. Both H.V. and L.V. sides may be connected in Star or Delta, but only the following regular combinations are permissible :—

No. 1 *Transformer.*	*No.* 2 *Transformer.*
(*a*) Star—Star.	Star—Star.
(*b*) Delta—Delta.	Delta—Delta.
(*c*) Star—Star.	Delta—Delta.
(*d*) Star—Delta.	Star—Delta.
(*e*) Delta—Star.	Delta—Star.
(*f*) Star—Delta.	Delta—Star.

If any other grouping is attempted, a true short-circuit on the line will result.

11. Stock transformers suitable for use on a series of different voltages.—Although the star winding is economically the better, it is sometimes desirable to stock transformers suitable for use on a number of different supply systems. Suppose a star-connected winding to be insulated for 10,000V between lines and divided into six sections, the 12 ends of which are brought out conveniently for interconnection in any desired manner, then four arrangements are possible (Fig. 15).

That is, the transformer is suitable for use on four different voltages, three of which are British Standard voltages. Similar connections may be arranged for the L.V.

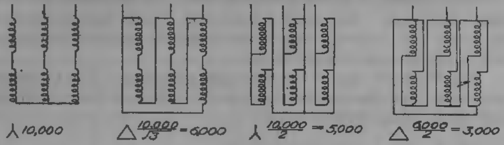
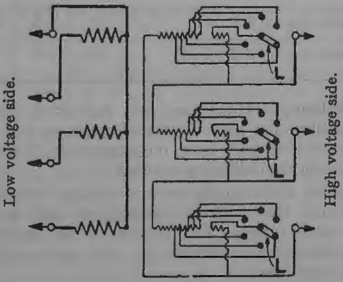


Fig. 15.

12. Transformers in series.—Owing principally to the increased voltage to which the windings would be subjected, it is not advisable to connect two separate transformers designed for voltage **V** in series to obtain a transformer suitable for use on a voltage of **2V.**

13. Tappings to alter transformation ratio.—Tappings are often useful to compensate for line drop; they may be placed either on the H.V. or L.V. side. H.V. tappings are more usual, being cheaper to provide, and, further, the adjustment can be made closer on account of the greater length of wire. Tappings to increase the voltage by 2½ and 5 per cent. are common; that is, if the normal voltage with the whole of the windings in use is 200, the H.V. tappings provide



Typical diagram of connections showing a 3-phase transformer with low voltage star-connected and neutral point terminal: high voltage mesh-connected with tappings. L indicates a removable link.

Permission of Messrs. Ferranti, Ltd.

Fig. 16.

for the voltages 205 and 210 on the L.V. side, when the normal H.V. voltage is supplied to the primary.

Care should be taken to ensure that the idle turns are not short-circuited. Too great a variation should not be worked to, since the capacity of a transformer is reduced when the whole of the copper is not in use.

Fig. 16 shows one of the best arrangements. The tappings are taken from the centre of the coil to allow of the reinforced end turns being always in use.

14. **Regulation.**—The actual secondary voltage of any transformer is less than the theoretical value, owing to magnetic leakage and ohmic loss in windings. The percentage decrease in secondary voltage from no load to rated (full) load is called the *Inherent* (*Voltage*) *Regulation* of the transformer. The following table gives representative figures for transformers of four different capacities. It will be noted that the regulation is adversely affected by low power factor.

Capacity of transformer in **kVA** ..	5	50	100	500
Per cent. regulation for P.F. of 1 ..	2·5	1·5	1·35	1·25
Per cent. regulation for P.F. of 0·8 ..	4·0	3·5	3·5	3·5

15. **Efficiency.**—This may be measured directly by means of wattmeters with the transformer on load or it may be determined indirectly from measurements of the iron and copper losses in the following manner :—

i. *Iron loss test.*—Apply normal voltage to one winding, leave the other open-circuited, and measure the watts taken. The current is so small that the power registered will be due practically to iron losses alone.

ii. *Copper loss test.*—Short-circuit the L.V. windings, and apply a low voltage to the H.V. windings. Increase applied voltage until normal full-load current passes. Observe the wattmeter reading which will be the copper loss on full load. The low voltage produces only a low induction in the iron, so that the iron losses are negligibly small.

When determining efficiency for acceptance testing, the copper loss should be computed for a mean temperature of the windings of 75° C.

When deducing the efficiency at various loads, it must be remembered that the iron losses are practically constant at all loads, but the copper losses are proportional to the *square* of the load current.

In the absence of precise information, the following table gives some idea of the efficiencies that may be expected at various loads and power factors :—

Capacity of transformer in **kVA.**		5	50	100	500
Efficiency at full load ..	P.F.=1	95	97·1	97·4	98·5
,, ,, ½ ,, ..	,, 1	94·7	97·3	97·7	98·4
,, ,, ¼ ,, ..	,, 1	92·2	96·3	96·8	97·9
,, ,, full load ..	P.F.=0·8	94	96·4	96·8	98
,, ,, ½ ,, ..	,, 0·8	93·5	96·7	97·1	98
,, ,, ¼ ,, ..	,, 0·8	90	95·5	96·1	97·4

16. **Financial aspect of losses.**—Low iron losses are particularly desirable in lighting transformers which are excited continuously and which have a low *load factor.* Conversely, low copper losses are specially important with power transformers with which the load factor is usually high.

The iron losses in a 100**kVA** transformer will be about 1**kW.** With energy at 2d. per unit the annual cost of these losses may be as much as $\frac{1 \times 8,760 \times 2}{240} = £73$ per annum.

When low rates for power are quoted by supply companies, the power supplied is usually metered on the H.V. side of the transformer, so that the consumer pays for the wasted energy. It is advisable, therefore, to switch off transformers when not actually required.

When purchasing transformers, efficiency must be carefully considered before accepting the lowest tender. The calculations given in Appendix V of D.W.S.S. (E. & M.) No. 14 will be found useful.

17. **Temperature rise** (*see* B.S. Specification No. 171).—This is usually determined by running the transformer on full load until a steady temperature is reached.

The following figures must not be exceeded :—

——	Maximum observable rise.	Maximum final temperature.
Insulation	55° C.	95° C.
Oil	50° C.	90° C.

The temperature of the coils is determined by resistance and that of the oil by a thermometer.

18. **Overload capacity.**—Standard makes of oil transformers, when designed for a full-load temperature rise of

50° C., will usually withstand the following overloads without injury.

Percentage overload.	Possible duration of overload.	
	Starting with transformer at atmospheric temperature.	Starting with transformer at working temperature.
15	5½ hours	3 hours
20	4½ ,,	2½ ,,
25	3¾ ,,	2 ,,
50	1¼ ,,	45 mins.
100	15 mins.	2 ,,

19. **Minimum insulation resistance.**—The insulation resistance should be measured with a voltage of about 500V (D.C.) applied for a sufficient time for the reading of the indicator to become steady. After the temperature rise test when the transformer is hot.

It should not be less in megohms than

$$\frac{\text{rated voltage}}{1{,}000 + \text{rated output (kVA)}}.$$

It is generally advisable not to apply the H.V. test when the insulation resistance is less than that indicated above.

High voltage tests (B.S.S. 171).

A. *At works.*—The test voltages at works are more severe than those applied on site, and, in addition, an induced high voltage test is applied to test the insulation between turns and between windings. For particulars of these tests reference must be made to the specification.

B. *On site.*—The tests should be taken after a temperature rise test while the transformer is hot. Although not mentioned in the standard specification, the insulation should not be less than that specified above, when the H.V. tests are applied. The test voltage should be alternating, preferably of the rated frequency. Its value should be $V = \frac{75}{100}(1{,}000 + 2V)$ volts, with a minimum of 1,500 volts, V being the service value for the winding under test. The appropriate voltage should be applied between each winding in turn and the core of the transformer, all other windings being connected to the core during the test. A low voltage should be applied to begin with, raised fairly rapidly to the specified value, ***maintained at this value for one*** minute, and then rapidly reduced before switching off. If such a high testing voltage is not available, the value may be as low as $\frac{55}{100}$ (1,000 + 2V) volts, providing that the time of application is increased to ten minutes.

High voltage test (Electricity Commissioners' Regulation No. 7).

. . . No machine, device, or apparatus shall be brought into use until its insulation has withstood the continuous application ***during half an hour*** of a voltage 50 per cent. greater than the maximum voltage to which it is intended to be subjected in use.

22. *Transformer sub-stations.*

1. When power at high voltage is taken from a civilian source the design of the transformer sub-station is usually a matter for the supply company, and the installation may be entirely under its control; but the cost is usually borne by military funds, and, therefore, the military engineer should understand what is necessary and sufficient for its equipment.

Under peace-time conditions no difficulty should be experienced in this connection if funds are available, *e.g.*, if draw-out truck type switchgear is installed and armoured cable connections are used between transformers and switchgear, the design calls for little comment. But the installation of expensive switchgear is not always justified in military sub-stations, which are usually of small capacity (less than **300kVA**). Moreover, it may frequently be necessary to control a power supply with a very limited amount of apparatus available, and it is therefore proposed to deal in some detail with the simplest types of installation, in which the building may be considered as a cubicle to which access is permitted only to skilled and trustworthy personnel.

2. Various types of switchgear have already been described in Chapter II.

The following are the principal guides in designing a sub-station in relative order of importance :—

i. Safety of operating personnel.
ii. Freedom from breakdown.
iii. Minimum fire risk.
iv. Reasonable first cost.

3. **Safety of operating personnel.**—The *Home Office Regulations* referred to in Sec. **16**, para. **2**, should be carefully studied and invariably complied with. Cases will rarely arise, even under active service conditions, when compliance with these regulations is not possible.

A sound rule is to arrange that the danger is at once obvious when entering a building and to have exposed live wires on one wall only. In the internal H.V. wiring, bare conductors are preferable in that they are obviously dangerous, and *all H.V. conductors should be treated as live whether insulated or not.*

It is not always realized that a severe static shock may be obtained from contact with an insulated H.V. wire, unless the insulation is surrounded by an earthed metallic shield, such as a lead sheath or armouring.

4. **Freedom from breakdown.**—To ensure this, efficient apparatus should be installed and sufficient clearances provided. The minimum distance between bare conductors and between bare conductors and walls should be 6 inches for 6,000V and 9 inches for 20,000V. Clearances between isolating switches and between fuses should be at least 12 inches at 6,000V and 18 inches at 20,000V. *Ventilating holes should be covered with close-meshed netting to prevent access of vermin.*

5. **Minimum fire risk.**—All buildings, apparatus, and fittings should be of incombustible material. Paper and oil are unavoidable in transformers and switches and do not introduce any appreciable fire risk, but bare wire with air and porcelain only as insulation should, wherever practicable, be used for the H.V. internal wiring. In the rare cases where insulated wire is necessary, an asbestos covering should be used above the rubber insulation. Good ventilation should be provided to assist in the cooling of the transformers and to prevent the accumulation of any explosive mixture which might be formed if the transformers are worked hard. The transformers should be placed on girders to ensure a few inches clearance above the floor to assist air circulation.

6. **Reasonable first cost.**—When the projected installation is a permanent one, too much stress should not be laid on the question of first cost. But for temporary work, as long as reasonable personal safety is provided for, very crude transformer houses of wood and corrugated iron, with simple fuse protection, are quite satisfactory; the fire risk is small.

The installation of transformers on poles leads to great economy, since the expense of a building is avoided at the cost of an extra pole or two. This type of construction is very suitable for quickly-required temporary installations up to **10kVA** capacity; it may also be used in permanent work for scattered lighting and isolated machines, such as pumps and circular saws.

Pole transformers are not recommended for permanent installations requiring more than **10kVA**, but in temporary work it is quite practicable to mount 100kVA transformers in this way.

7. Leading in from overhead lines.—The following are the methods which may be adopted :—

i. Through a porcelain tube in the wall.
ii. Through a large hole in the wall with wire secured to shed-type insulators.
iii. By underground cables (*see* Pl. **39**).

Method (ii) is better than method (i), and both are cheaper than method (iii), but they necessitate high buildings, since bare conductors must not be brought within less than 20 feet from the ground ; this requirement alone generally precludes their adoption for sub-stations. Method (iii) is the most satisfactory and is universally applicable ; moreover, it is frequently necessary in densely populated areas where H.V. overhead lines are undesirable.

8. Methods of rendering a sub-station safe before working therein.—If it is convenient to cut off the current from outside the building, a 3-pole airbreak earthing switch should be placed inside near the leading-in trifurcating box for the purpose of earthing the cable end as soon as notification is received that it should be dead. This will prevent voltage being maintained if the supply should inadvertently be switched on while work is proceeding.

If it is not possible to break the circuit externally, the leading-in cable trifurcating box may be carried up as high as possible, and isolating switches placed so that, when they are open, the live terminals are more than 8 feet from the ground (*see* Pls. **39** and **40**).

Another method is to install the trifurcating box low; and to place it, together with a 3-pole disconnecting switch, inside a separate iron cubicle with expanded-metal front. The switch contacts should be visible, and the control handle should be provided with a locking arrangement.

If there is a bank of transformers, each transformer should be installed in a cubicle, and isolating switches should be placed on both H.V. and L.V. sides in the cubicle to enable a workman personally to ensure his own safety when it becomes necessary to overhaul one transformer without interrupting the supply. It may not be superfluous to emphasize that a transformer is just as dangerous when connected up on the L.V. side only as when connected to the H.V. mains, and, when the only L.V. switch is on a board out of sight of the workman, he should not be expected to stand the risk of it being closed inadvertently.

9. Typical transformer sub-stations.—For military purposes where personnel is liable to frequent and sudden changes, an open type of installation, where all the danger is visible, is preferable. Plenty of space and ample clearances are advisable.

Pl. **39** shows a simple transformer cabin suitable for 3-phase loads up to 50**kVA**. The transformer is controlled on the H.V. side by isolating switches and fuses only. When the switches are open, there are no live wires or contacts within 8 feet of the floor. L.V. switches, fuses, and meter (when fitted) are installed in a weatherproof iron or wooden box outside the building. For permanent work the building should be of stone, but for temporary installations wood or corrugated iron gives satisfactory service.

Pl. **40** gives a suggested arrangement for loads up to **300kVA**, which is about the largest sub-station capacity likely in military work. A single automatic oil circuit-breaker is provided for protection on the H.V. side. The circuit-breaker is controlled from the L.V. switch-room, and the circuit-breaker escutcheon (with trip coils), relays, and integrating wattmeter are installed one above the other on the same panel. No other instruments are necessary on the H.V. side; one pair of current transformers is for the meter (and ammeters if required) and the other for the oil circuit-breaker. The voltage transformers are for the meter (and voltmeter if required). There is no real necessity to install automatic oil circuit-breakers or fuses on each individual transformer when they are working in parallel on both H.V. and L.V. sides. They may serve a useful purpose if an internal fault develops in a transformer, but this is of rare occurrence.

The L.V. switchboard should be fitted with one voltmeter, one set of switches and fuses for each transformer and feeder panel, one ammeter for each transformer and power feeder, and three ammeters for each lighting feeder.

The compartment behind the L.V. switchboard can be used for the installation of lightning-protection apparatus if considered necessary. In most cases such apparatus can be fitted on the overhead line, and then a 15 by 5 feet compartment is available for the L.V. switchgear.

Pl. **41** shows a 7½**kVA** single-phase 6,000V transformer mounted on poles. The transformer is fitted with glass-tube fuses inside the casing.

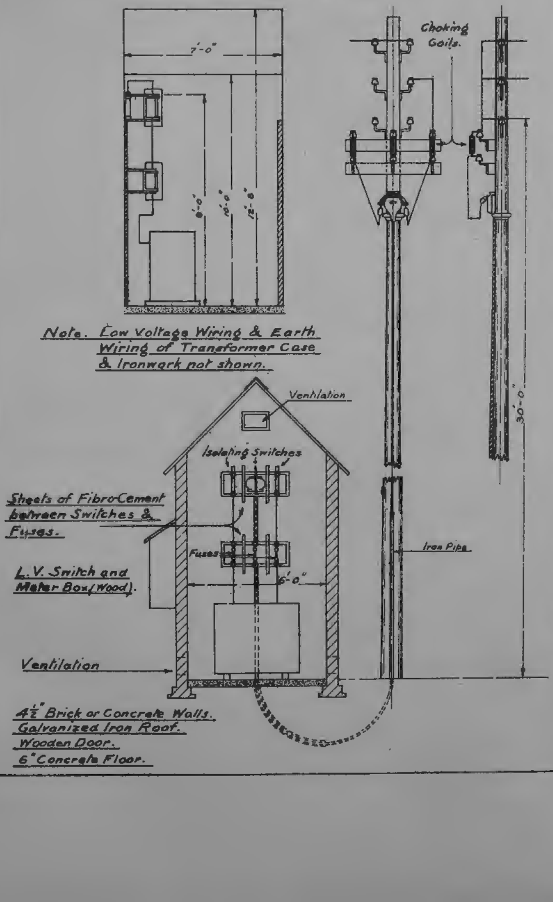
It may be noted here that it is now becoming common civilian practice to install outdoor type weatherproof transformers and H.V. switchgear of all sizes and voltages in the open in a railed-in enclosure, providing a small building only for the L.V. switchboard. This arrangement may sometimes be suitable for military purposes.

10. **Kiosk sub-stations.**—In recent years a steel plate *kiosk* type of structure has been introduced and is used very

[Tof [To face p. 118.

Plate 39.

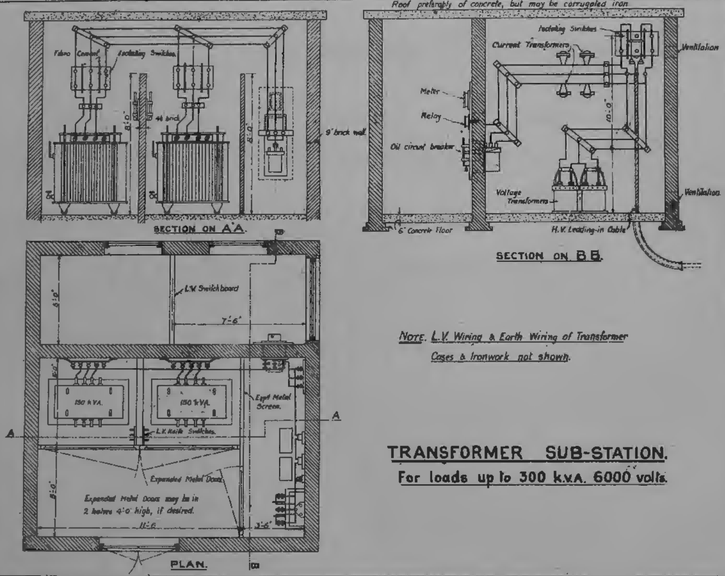
TRANSFORMER SUB-STATION.
FOR LOADS UP TO 50 KVA.
6,000 Volts. Three-Phase.



Note. Low Voltage Wiring & Earth Wiring of Transformer Case & Ironwork not shown.

4½" Brick or Concrete Walls.
Galvanized Iron Roof.
Wooden Door.
6" Concrete Floor.

Plate 40.



SECTION ON A'A.

SECTION ON B.B.

PLAN.

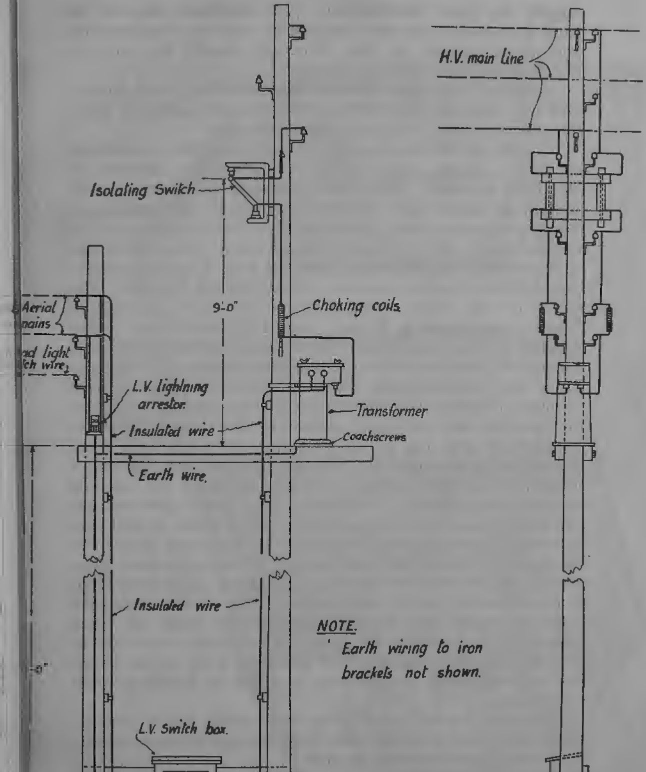
NOTE. L.V. Wiring & Earth Wiring of Transformer Cases & Ironwork not shown.

TRANSFORMER SUB-STATION.

For loads up to 300 k.v.a. 6000 volts.

PLATE 41.

METHOD OF MOUNTING SMALL TRANSFORMER ON POLES.



NOTE.
Earth wiring to iron brackets not shown.

largely for rural distribution. (The methods adopted for rural distribution are very suitable for military requirements, and developments in this direction should be carefully watched.)

A kiosk is cheaper than a brick building, and from a military point of view it is a very attractive design, being transportable and easily and quickly erected.

Pls. **42** and **43** show a good, though somewhat special and expensive, design for a **300kVA** sub-station installed at Stretford in 1926. The kiosk consists of a strong self-supporting angle- and flat-iron framework surrounded by heavy gauge steel plate, the whole forming a substantial and weatherproof arrangement. The overall dimensions are approximately as follows: base, 12 feet 6 inches square; height, 8 feet 3 inches to eaves, 10 feet 6 inches to ridge. The depth of the three compartments are H.V. switchgear, 5 feet; transformers, 5 feet; and L.V. switchgear, 2 feet 6 inches. The vertical members of the framework are let into 9 inches by 9 inches concrete foundation blocks to a depth of 1 foot, and when the kiosk is erected, a concrete plinth is made up inside, 3 inches above ground level and extending 5 feet outwards on the two switchgear sides of the building. The doors at the front and rear are divided into two portions, the top portion being arranged for opening upwards and forming a shelter, whilst the lower portion is designed for opening downwards to form a platform. The upper portions are provided with stays for supporting the door when opened, and in addition hooks are fitted so that weatherproof sheets can be rigged up round the door to protect the attendant when working under adverse weather conditions. The lower door giving access to the L.V. switchgear is fitted on the inside with a fluted rubber mat for the attendant to stand on when inspecting or repairing the gear. The bottom doors are of thicker steel than that used for the main body of the kiosk, and are reinforced to eliminate any risk of buckling when stood upon.

Porcelain bushes are fitted at those points where connections (ozone proof rubber tails) pass through division screens from one compartment to another.

Adequate ventilation is ensured by the provision of louvres which are protected to prevent the entry of rain, snow, sleet, &c.

H.V. switchgear.—The H.V. switchgear shown in Pl. **42** is designed for controlling the supply taken from a ring main cable system to the power transformers. There are two oil-immersed isolating switches and two oil circuit breakers with overload and leakage protection. The instruments provided are two voltmeters, two ammeters, and two watt-hour meters.

PLATE 42.

KIOSK SUB-STATION—HIGH-VOLTAGE SIDE. *[Permission of Ferguson, Pailin, Ltd.*

[To face page

To face p. 121.]

PLATE 43.

KIOSK SUB-STATION. LOW-VOLTAGE SIDE.

[Permission of Ferguson, Pailin, Ltd.

P3825

KIOSK SUBSTATION.

LOW VOLTAGE CONNECTIONS.

(See Section 22)

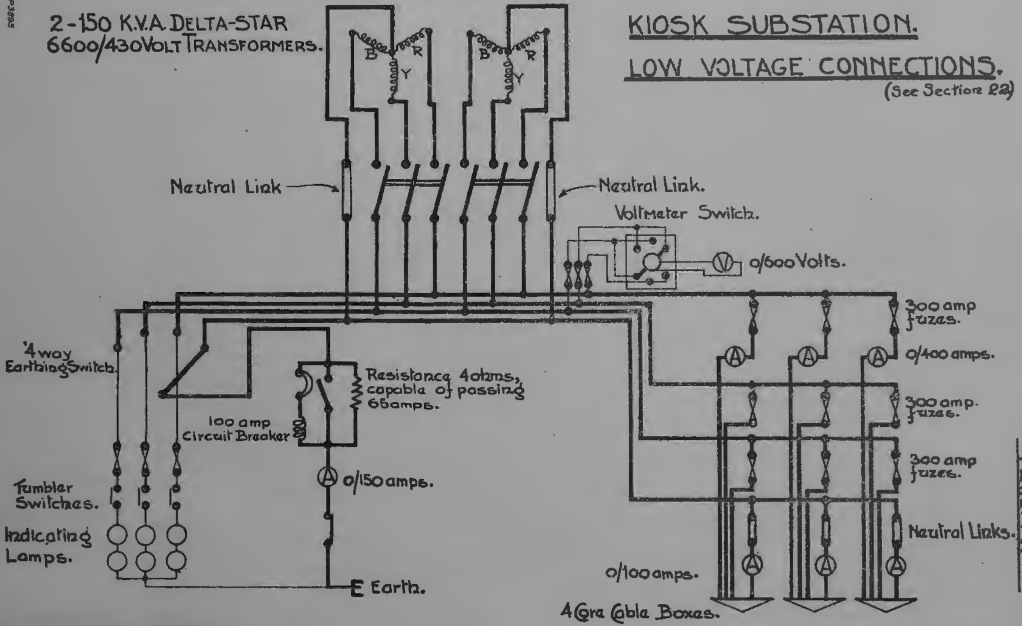


PLATE 44.

To face p. 121.]

Power transformers.—The two 150kVA, 3-phase, 50-cycle transformers have a ratio of 6,600/430 volts and are connected delta star. They are of the oil-immersed self-cooled indoor type.

L.V. switchgear. (Pls. **43** and **44**).—The switchboard on the low voltage side consists of a distribution panel, transformer panel and earth testing panel. Each of the latter two panels comprises an angle-iron framework equipped on the front with 1½-inch thick black enamelled slate slabs for supporting the switchgear.

The distribution panel consists of three "Henley" distributor units each comprising two micanite insulated parallel steel tubes coupled together at top and bottom to form a rigid support for the fuses and neutral link. An ammeter is fitted in one phase and also in the neutral of each feeder.

The transformer panel is equipped with two main knife switches for the supplies from the two power transformers and also a link for each neutral. In addition a voltmeter is fitted complete with change-over switch to enable the voltage to be read between phases.

The earth testing equipment consists of a S.P. automatic air break overload circuit breaker, two single-pole knife switches, ammeter and earthing resistance. A four-way selector switch is provided for connecting any one phase or the neutral to the earthing equipment. The three phases are joined and the common point earthed, and between each phase and the common point is inserted a fuse, tumbler switch and two indicating lamps in series.

The earthing equipment is arranged so that normally the circuit breaker short circuits the resistance, but immediately a fault occurs and the current to earth exceeds the predetermined value, the breaker opens and thus inserts the resistance in circuit. The resistance is designed to limit the current to 65 amps. The ammeter indicates the value of the earth current at any instant. When it is necessary to maintain the supply for some time with a low resistance earth fault, the selector switch may be connected to the faulty phase. One of the knife switches is used for definitely short circuiting the breaker and resistance when required, and the other one for disconnecting the whole of the equipment from earth.

Screens are provided at the sides of the board to prevent accidental contact with live metal.

The above design has been somewhat fully described as it presents several interesting features, but the tendency appears to be to use a simpler and more compact design of both building and switchgear equipment.

But however desirable this may be to secure an economical construction, this should not be obtained by disregarding the risk of danger to the attendant, who may have to carry out work in semi-darkness or in bad weather, which increases the normal risk.

Pl. 45 shows a simpler design of about the same **kVA** capacity, but space does not permit of a full description. It may be noted, however, that the isolating switches are of the simple air-break type, and the overall dimensions are: length 7 feet 6 inches, depth 8 feet 3 inches, and height 8 feet 11½ inches.

It may be noted that earth testing equipment on the scale described above must be considered as a luxury, and its expense would seldom be justified except in very large sub-stations.

23. *Prevention of danger from contact between H.V. and L.V. circuits.*

1. Supply Companies are legally compelled to provide safety arrangements to prevent danger to life from contact between H.V. and L.V. circuits.

Regulation No. 20 of the Home Office Regulations for Factories and Workshops deals with the matter as follows :—

> Where a H.V. or E.H.V. supply is transformed for use at a lower voltage, or energy is transformed up to above low voltage, suitable provision shall be made to guard against danger by reason of the lower voltage system becoming accidentally charged above its normal voltage by leakage or contact from the higher voltage system.

Regulation No. 9 of the E.C. Regulations (El. 38) for securing the safety of the Public, states :—

> In every case where a H.V. supply is transformed for the purpose of supply to one or more consumers, some suitable automatic and quick acting means shall be provided to protect the consumer's wires from any accidental contact with or leakage from the H.V. circuit either *within* or *without* the transforming apparatus.

2. Before describing the methods adopted to comply with these regulations, it is necessary to refer to another effect which must also be guarded against. The primary and secondary windings of a transformer, being separated by a dielectric, constitute a condenser with the result that electrostatic phenomena may be produced in the secondary, this effect being in no way due to insufficient insulation. Normally this effect is negligible, but under severe fault conditions, such as the breakdown of a H.V. insulator, very high voltages may be induced in the L.V. system. This effect is most marked with transformers having a high ratio of transformation, *e.g.*, 20,000/200.

Dealing first with insulation faults within the transformer, it was formerly customary to place between the H.V. and L.V. windings a thin sheet of metal known as an *earthing shield*, well embedded in the insulation and connected directly

PLATE 45.

[*To face p.* 122.

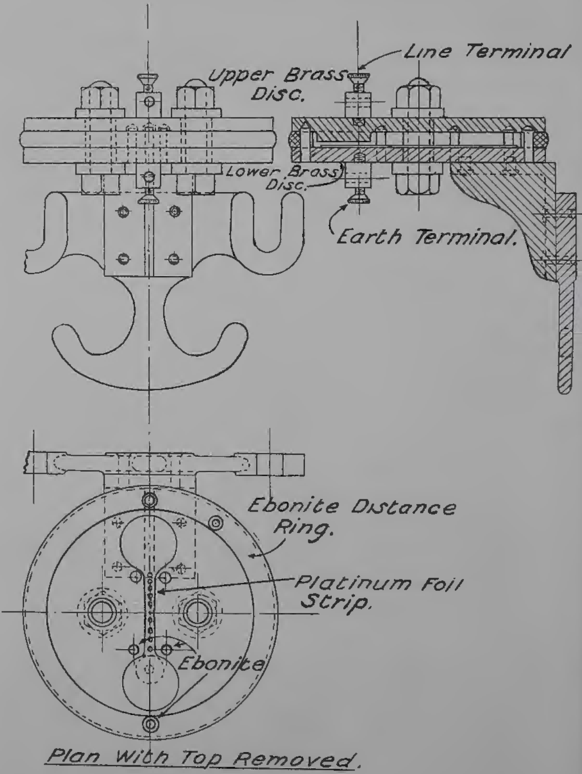
KIOSK SUB-STATION.

[*Permission of Ferguson, Pailin, Ltd.*

PLATE 46.

CARDEW EARTHING DEVICE.

Scale, half size.



with earth. This method of protection is not now considered good practice; it presents difficulties from a constructional point of view and does not prevent trouble from contacts on the mains. As far as the transformer itself is concerned, better results are obtainable by insisting on a high dielectric strength between windings (*see* transformer tests), in which case breakdowns are extremely rare.

3. Sometimes an *earthing device* is connected between the secondary winding and earth, either in place of or in addition to an earthing shield, in order that, should the voltage between this (L.V.) winding and earth rise above a certain value (owing to contact between primary and secondary), the latter may be automatically earthed. The Cardew earthing device is illustrated on Pl. **46.**

When the L.V. circuit becomes charged to a dangerous voltage, a platinum foil strip, normally lying loose on the lower plate, is attracted up and makes contact between the two discs, thus putting the line to earth. A certain amount of metal is fused, and the line, therefore, remains in contact with earth until the surfaces are cleaned up again. The discs are of large area to increase their capacitance and, therefore, the attractive force.

This apparatus provides protection against contacts on the mains as well as in the transformer, but it is not entirely satisfactory, particularly with overhead lines, since a lightning discharge or other electro-static phenomena due to faults on the H.V. line may cause it to function, and so put a permanent earth on the line. Efficient spark-gap lightning arrestors should only earth the line temporarily.

4. The most satisfactory safety arrangement which renders the L.V. system safe from faults (both without and within the transformer) and from capacitance effects is to **earth some point on the L.V. system.**

24. *Earthing.*

1. The following are the **principal reasons for earth connections** in electricity supply systems :—

i. *To fix the potential of metal which might become " alive " due to breakdown of insulation or to electro-static or electro-magnetic induction.*

Under this head come switchboard frames, switch cases, lead covering and armouring of cables, joint boxes, metal conduits, motor and generator frames, transformer tanks, iron brackets supporting insulators, guardwires, stays, &c.

The various regulations of the Electricity Commissioners, The Home Office, and the Institution of Electrical Engineers, all require this precaution to be taken, to prevent danger from shock and fire.

ii. *To connect lightning arrestors with a point of zero potential.*

iii. *To fix the potential of some point in the system itself.*

The point usually connected to earth is the *neutral* of the system.

2. The **advantages of earthing the neutral** are :—

i. The voltage between line and earth is limited to 58 per cent. of the effective transmission voltage between wires in the case of 3-phase and to 50 per cent. in the case of single-phase 3-wire systems. On H.V. circuits these limitations are of no appreciable value in reducing danger of shock, but they lead to economy in line insulation at very high voltages.

On L.V. circuits these limitations secure economy in copper, without increase of shock risks, by permitting distribution at a higher voltage between conductors than would be possible without the neutral earth connection.

ii. Earth faults on the lines can be instantly detected, and the faulty lines can be automatically disconnected if desired.

iii. When the neutral of the L.V. system is earthed, it reduces risk of dangerous shock due to leakage between H.V. and L.V. systems.

iv. It obviates the necessity for leakage devices for protection against static lightning effects.

3. **The disadvantages of earthing the neutral** are :—

i. An earth fault on one line results in a short circuit on the system.

ii. There is more danger of resonance in H.V. systems with low frequencies.

iii. Telephone systems may be affected by leakage currents. This trouble is minimized if the system is earthed at one point only.

4. Engineers are not yet agreed as to the wisdom of earthing the neutral of H.V. systems.

In permanent military installations erected with peace-time safeguards, it is probably better to run with neutral earthed through a current-limiting resistance ; but a hand-operated switch should be provided to break the neutral earth connection if it is desired to maintain the supply temporarily with appreciable leakage on the line.

In temporary military installations in which the lines are exclusively overhead, it may be found advisable to run with neutral insulated.

5. The Electricity Commissioners' Regulations concerning the connections of circuits with earth.

Continuous current circuits.

Where the voltage of a supply between the adjacent conductors of a three-wire continuous current system of mains exceeds 125 volts, the intermediate conductor shall be connected with earth, in accordance with the following conditions :

(*a*) *The connection with earth of the intermediate conductor shall be made at one point only* on each distinct circuit, namely, at the generating station or substation, and *the insulation of the circuit shall be efficiently maintained at all other parts.*

(*b*) The current from the intermediate conductor to earth shall be continuously recorded, and if at any time it exceeds one-thousandth part of the maximum supply current, steps shall be immediately taken to improve the insulation of the system.

Alternating current circuits.

Alternating current circuits may, with the approval of the Electricity Commissioners and with the concurrence of the Postmaster-General, be connected with earth in accordance with the following conditions, &c. :—

I. General.

(*a*) *The connection with earth shall be made only where energy is delivered to each circuit*, that is to say, at a generating station, a sub-station or transformer, and shall, wherever practicable, be made at a neutral point in the circuit and in such a manner as will ensure at all times an immediate and safe discharge of energy.

(*b*) The connection with earth shall be efficiently maintained, except when it is interrupted by means of a switch or link for the purpose of periodical tests for ascertaining whether any current is passing by means of the connection with earth.

(*c*) *The insulation of the mains shall be efficiently maintained at all other parts.*

(*d*) Tests shall be periodically made to ascertain whether any current is passing by means of the connection with earth, and if at any time the current so passing exceeds one-thousandth part of the maximum supply current of the circuit, steps shall immediately be taken to improve the insulation.

II. Additional Clauses for E.H.V. Circuits.

(*a*) If the neutral is connected with earth through a resistance, the resistance shall be sufficiently low to ensure that the fuse or automatic circuit-breaker in the mains shall act.

(*b*) If the neutral point is not connected with earth, a separate electro-static voltmeter, placed in a conspicuous position in the generating station, shall be connected between each distinct circuit and earth; and if the indications of the voltmeter show that the insulation of any of the circuits is faulty, immediate steps shall be taken to restore the insulation.

6. **Necessity for care in making earth connections.**—The following remarks embody the recommendations of the Home Office, Electricity Commissioners, and the Institution of Electrical Engineers.

It is most important that proper care be taken in making the earth connection. The perfunctory manner in which earthing has often been carried out has led to fatal accidents.

It is generally agreed that a water-supply system, if extensive, offers the best means of making the connection. Earth plates when used must be of sufficient size, having regard (*a*) to the current which they may have to carry, and (*b*) to the nature of the ground and its condition as regards moisture. Permanently wet ground is obviously the best in which to bury the earth connection. Earth plates may be of copper, cast-iron, or galvanized-iron plates. They are placed preferably in an upright position in the ground, and should be completely surrounded by a bed of 12 inches of broken coke or carbon packed hard (the ends of arc lamp carbons are suitable for this purpose). The depth at which they should be buried depends upon the condition of the ground in regard to moisture, but the top of the coke bed should not be, in general, less than 4 feet from the surface. The coke increases the effective area of the earth connection practically to that of the outside of the coke bed. Impregnating the coke and the surrounding ground with a solution of salt will materially reduce the resistance of the earth connection. Where salting is relied upon, the treatment should be repeated at intervals when periodical tests show that it is needed.

It is worse than useless to bury earth plates in chalk or rock, and it may be necessary to take a connection some distance to a suitable position which should preferably be in marl or clay kept permanently wet by natural means.

In chalk, an alternative is to sink a bore-hole. At Bulford it was necessary to bore through a layer of over 200 feet of chalk before a good enough earth connection could be found.

No earth plate should be less than 4 square feet in area, and plates as large as 5 feet by 3 feet are sometimes used on large installations.

If the earth plate offers too great a resistance or there is a high resistance or disconnection in the earth wire, a portion of the earth wiring may be raised to a dangerous voltage. Therefore, bad connections in the earthing system render the installation more dangerous than it would be with no earth wires at all.

As so much depends upon the earth connection being in order, and as the earth plate is necessarily out of sight, it is advisable always to provide duplicate plates some distance apart. The best arrangement for a generating station is to provide two earth plates as well as a connection to the water-supply system. The individual resistance of each earth connection can then be ascertained by simple testing, which should be carried out regularly, and records kept. A link should be placed in each earth connection to facilitate this testing.

The earth wires should be adequately protected from mechanical injury and should be of ample cross-section. It should be remembered that if a fault occurs a considerable current may flow through the earth wire, causing dangerous overheating if it is too small.

It is desirable, therefore, that the earth wires should not be laid against inflammable material and that they should be visible throughout. In H.V. work the earth wire or strip should have a conductivity at all parts equal at least to 50 per cent. of that of the largest conductor used to supply the apparatus which it is desired to earth. But no earth wire should have a cross-sectional area of less than 0·022 square inch (7/16). The lead covering and steel armouring of cables may be used as an earth wire if they are electrically continuous (*i.e.*, efficiently bonded at all joints) and comply with the figures given above for conductivity. In L.V. and M.V. installations nothing smaller than 14 S.W.G. copper wire should be used.

In practice a stranded copper wire or a copper strip is run throughout the installation, and all metal work, &c. jointed thereto. All joints and connections must be well made. The connections with the metal which has to be earthed should be by sweated lugs and screw or clamp connectors which cannot work loose. Similarly, the connections of the earth wire to the earth plate must be so made that they cannot work loose or corrode.

When connecting to a water main, the wire should be sweated into a lug attached to a suitable metal clamp bolted tightly to the pipe, the contact surfaces of the pipe and the clamp being previously well scraped and cleaned. The connection should be made on the street side of the meter and main stop-cock.

Pl. **47** shows a form of earth connection which could be adopted for large generating stations, where the soil is of such a nature that a low resistance earth cannot be obtained with a simpler arrangement.

For small sub-stations and for earthing the continuous wire carried above transmission lines for lightning protection, an earth plate 2 feet square buried 6 or 8 feet underground in a bed of coke is generally sufficient.

A resistance of less than 1O should be aimed at in generating stations, and 2O should not be exceeded in substations.

25. *Protection of line and machinery from the effects of lightning, &c.*

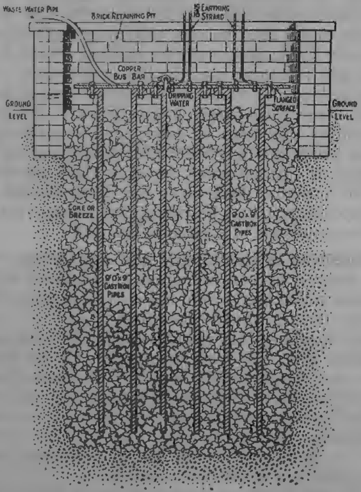
1. In practical working the machines, apparatus, and cables are often subjected to abnormal voltage rises. These voltage rises may be of external or internal origin, *i.e.*, they may be due to atmospheric electricity (in the case of overhead lines) or they may be due to disturbances in the system itself, due to faults or switching operations.

2. **Atmospheric electricity.**—A lightning discharge was formerly thought to be oscillatory, but it is now established that although there may be some relatively small high frequency ripples superimposed, the main discharge is invariably unidirectional. The resulting travelling waves on the line, however, have *very steep fronts*, in which the point of zero potential may be only a few hundred feet in front of the point of maximum potential. In a straight conductor this does no harm, but in a motor or transformer this difference of potential may be applied between two turns which are close together and separated only by a layer or two of cotton. In order to prove destructive, this wave need only have the potential necessary to perforate the insulation between wires, say, a few hundred volts, although the machine may be insulated to withstand several thousand volts to earth. For this reason the insulation on the end turns of transformer coils is generally increased as a measure of protection against these effects.

3. **The object of protective devices.**—Protective devices should reduce both the *amplitude* of the surge and its *potential gradient*. The former, which is the maximum potential difference between conductor and earth, causes

PLATE 47.

SUGGESTED TYPE OF EARTH CONNECTION FOR GENERATING STATION.



flash-over of line insulators, whereas the latter, which is the slope of the wave front (*i.e.*, the rate of change of potential along the conductor) causes breakdown of transformer insulation.

The apparatus should arrange for the dissipation of the energy of the surge, and when it functions it should not become the seat of further disturbances.

4. **Devices to deal with static charges.**—To prevent the accumulation of static charges in the system, the best procedure is to earth the line permanently and so allow the charge to leak away as continuous current.

5. **Line protection by earthed wire.**—A continuous earthed wire is generally installed near the line conductors. To be of any use it must be very efficiently earthed, preferably at every pole. The object of this earthed wire is to create a region of zero potential near the line conductors. Its effects are (i) to reduce the value of voltages induced in the line conductors due to discharges in the vicinity, (ii) possibly to divert a direct discharge to earth and so prevent the line itself from being struck. Statistical data leave no doubt as to the value of earthed wires, for after their installation the number of insulator flash-overs has been greatly reduced. Roughly speaking, it may be taken that a single earthed wire reduces the amplitude of a surge to one half.

6. **Protection of machinery and apparatus.**—So-called *lightning arrestors* or *tension limiters* are required to deal with disturbances which are beyond the control of the earthed wire and leakage devices already described.

Broadly speaking, they may be divided into two categories: (*a*) *Discharge* type, (*b*) *Absorption* type. Of the former type there is a very large variety, most of which are based upon the assumption that lightning discharges and other forms of surge are of high frequency and high voltage, and that therefore they will jump a small air gap to earth rather than puncture or flash over insulators or penetrate the highly inductive windings of electrical machinery.

The air gap forms an artificially weak point which acts as a safety valve, breaking down at a lower excess voltage than that which the insulation of the system will safely withstand.

The factor of safety of the system insulation to a transient excess voltage depends upon the duration of this voltage, and therefore the sooner the surge is cleared, the better. The shape of the spark gap electrodes is of great importance in this connection, the horn type of gap (Pl. **48**, Fig. 1) which has been so largely used in the past having a relatively large dielectric spark lag. There is no space available to go into

Plate 48.

LIGHTNING ARRESTORS.

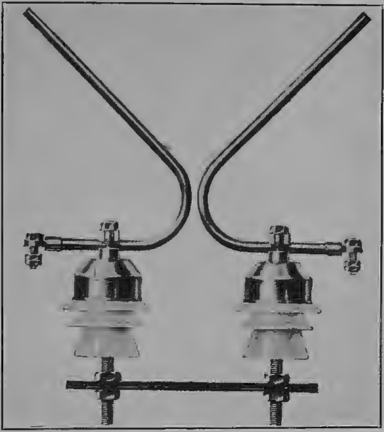
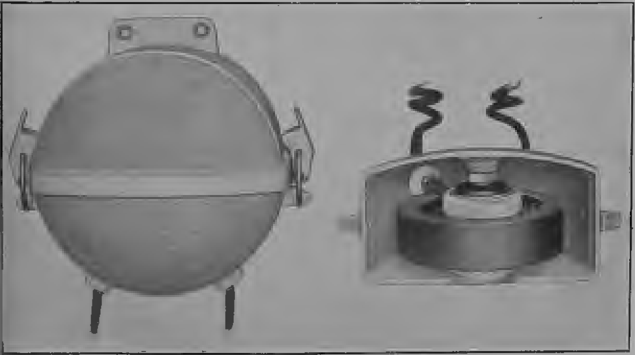


Fig. 1.—Plain Horn Gap. 6,000 volts.



Exterior.

Interior.

Fig. 2.—Multi-Path Arrestor. (For A.C. or D.C. circuits not exceeding 650 volts.)
(Indoor or Outdoor Mounting.)

[*Permission of Metropolitan Vickers, Ltd.*

OXIDE FILM LIGHTNING ARRESTORS.

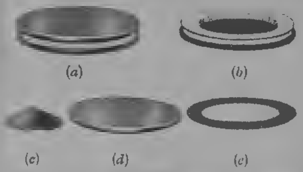
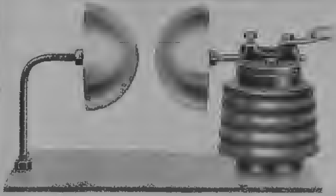


Fig. 1. ARRESTOR CELL



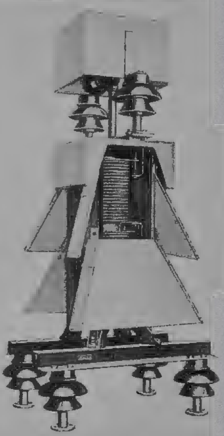


Fig. 2.—Typical Hemispherical Series Gap as used on Indoor Arrestors. 7,500–15,000 volts.

Fig. 3.—Typical Phase Unit of an Outdoor 3-Phase Arrestor not exceeding 7,500 volts.

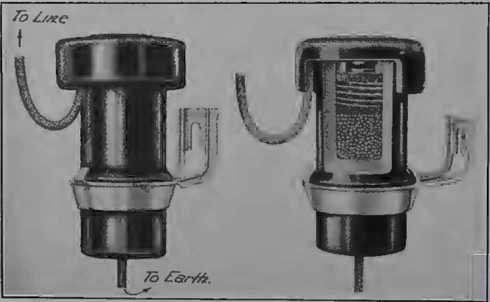


Fig. 4.—Complete. Fig. 5.—Showing part interior.

Typical Single-pole Pellet Oxide Film Type Arrestor 1,000–3,000 volts.

[*Permission of The British Thomson-Houston Co., Ltd.*

this matter fully here, but it may be stated that the sphere gap (Pl. **49**, Fig. 2), which is used in all the better modern types of discharge arrestor, has the following advantages over the horn gap :—

(*a*) It has less time lag.
(*b*) Its arc-over voltage is independent of the frequency of the voltage.
(*c*) It makes possible closer calibration.
(*d*) It is more stable.

Unfortunately this simple spark gap arrangement does not always afford protection against steep-fronted waves, since to be destructive these need not be of sufficient amplitude to jump the gap.

Moreover, when they function they put the line to earth, and much ingenuity has been exercised in the methods adopted for suppressing the surge due to the supply voltage which follows the lightning discharge.

7. The horn-gap arrestor.—This is the type of discharge arrestor which has been most extensively used in the past, mainly on account of the simplicity of its design and of its cheapness. The surge discharge takes place across the narrowest portion of the gap, and the power arc which follows is suppressed by the action of the horns. The arc travels rapidly upwards, partly by heat convection and partly by electro-magnetic action, until its length becomes too great for the supply voltage to maintain. A non-inductive resistance is connected in the earth connection to keep down the current in the power arc.

It is now definitely established that, although this type of arrestor may possibly serve a useful purpose on exposed portions of an overhead line to minimize damage to the insulators and supports of the line itself, it is of very little use for the protection of machinery, which should be the main function of lightning arrestors.

8. The oxide-film arrestor.—This is also a discharge type of arrestor, but it is a great improvement on the old-fashioned arrangement of horn-gap and plain series resistance. It makes use of the fact that lead peroxide (PbO_2) is a relatively good conductor (specific resistance 1 ohm per cm. cube), whereas red lead (Pb_2O_3) and litharge (PbO), into which the peroxide is converted at 150° and 250° C. respectively, are practically insulators. (Specific resistance of red lead $= 24 \times 10^6$ ohm per cm. cube, and that of litharge is much higher.)

In the station type the apparatus comprises two essential elements: (*a*) a series gap, and (*b*) a number of arrestor

" cells " in series, each cell being suitable for a working voltage of 300.

(*a*) The *series gap* is necessary because permanent application of the working voltage would impair the working of the arrestor cells. A sphere gap is used for the reasons given above.

(*b*) *An arrestor cell* is made up of two circular metal discs, about 7 inches in diameter, crimped firmly to the edges of an annular piece of porcelain. The space in between the discs is compactly filled with lead peroxide. The discs are coated on the inside with a varnish film forming in effect an insulator. A typical cell is illustrated in Fig. 1, Pl. **49**; (*a*) shows a complete cell, (*b*) one disc crimped on to the porcelain ring, (*c*) a quantity of lead peroxide, (*d*) the second metal disc, and (*e*) a varnished washer that is laid between the disc and the top face of the porcelain.

When a lightning discharge sparks over the series gap a voltage is impressed on the cells and minutely punctures the varnish films on the metal discs. As soon as the films give way, a discharge current flows freely through the lead peroxide filling to earth. But the heat developed converts some of the lead peroxide to red lead or litharge, which, replacing the varnish film at the puncture points, increases the resistance of the cells again to a high value. The cells have, therefore, a valve-like action. With each succeeding discharge more points are punctured, and the original varnish film becomes a honeycomb structure which holds the oxide film in place. The oxide film has a dielectric strength corresponding with that of the varnish film, but the former is superior to the latter in respect of time lag and valve action.

Pl. **49**, Fig. 2, shows an indoor spherical spark gap, and Fig. 3 a typical complete single-phase outdoor unit for **7,500** volts. The overall dimensions of this particular size are approximately 2′ 6″ × 2′ 6″ × 5′ high.

9. **The pellet oxide film arrestor.**—This is a smaller and cheaper design primarily intended for the protection of distribution transformers and moderate size sub-stations. It is made single pole and for outdoor service only.

The construction is shown in Pl. **49**, Figs. 4 and 5. The overall dimensions of the 1,000–3,000-volt size (for 3,000–5,000-volt systems with neutral point earthed) are 8 inches high, 5 inches diameter.

In this design the lead peroxide is formed into small pellets which are coated with litharge powder forming a film similar to the varnish film on the cell type of arrestor. The pellets are maintained in good electrical contact with one another, and with the metal electrodes at the top and bottom

LIGHTNING PROTECTION.

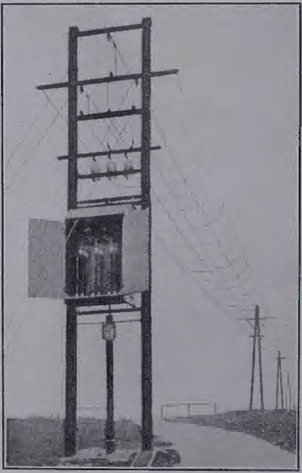


Fig. 1.—Terminal Pole with Moscicki Condensers.

of the column by means of a spring in compression. A series spark gap is mounted at the top of the container between the line connection and the pellet column.

10. **The use of condensers.**—The reactance of a condenser is inversely proportional to the frequency, and a small condenser, which will pass a negligible current at a frequency of 50, will pass quite a large one at a frequency of 100,000. A condenser connected between line and earth near the apparatus to be protected, without the intervention of any spark gap, is, therefore, an ideal device for dealing with high-frequency oscillations, moreover, it reduces the potential gradient of a steep-fronted wave which is similar in effect to a quarter cycle of a high-frequency oscillation.

The *Moscicki* type, in which the dielectric is a glass tube, has been the most popular and is suitable for working voltages up to 40,000. A condenser of this type having a capacitance of 0·0011μF has an overall length of about 2 feet and a diameter of 2½ inches. In practice a number of such units are used in parallel. Pl. **50** shows a terminal pole of the H.V. 3,000-volt line from Tidworth to Bulford. A battery of 4 unit condensers is connected to each line.

Since a condenser of appreciable capacitance is obtained from a comparatively short length of insulated underground cable, it is advantageous to lead in from an overhead transmission line to generating or sub-stations through a length of 200 or 300 feet of cable.

11. **Use of choking coils.**—When a discharge type of arrestor is connected between line and earth in or near generating or sub-stations, a choking coil is usually connected in series with the apparatus to be protected. Since the reactance of an inductance is directly proportional to the frequency, a choking coil which has a negligible reactance at the supply frequency of 50 will naturally have a very large value at a frequency of the order 100,000, and will tend to reflect high-frequency surges and smooth out steep-fronted waves. An inductance in series therefore produces an effect similar to that of a condenser in parallel with the apparatus to be protected, but it must be pointed out that the type of choking coil commonly used, consisting of an air-cored helix of 20 to 30 turns of bare copper wire from 4 to 10 inches in diameter, has an inductance of the order 0·00002 to 0·0001H only, which is too small to be of much practical value. To produce the same effect as a condenser of 0·01μF, an inductance of 0·01H would be necessary, and this would generally cause an excessive voltage drop with the normal supply current and frequency.

In the case of small transformer stations, however, quite large reactances are permissible, but to keep down the cost and bulk, it will be necessary to construct them of a large number of turns of insulated copper wire. Iron cores should not be used.

It is sometimes advanced that if a surge originates inside the power station or sub-station, choking coils may do more harm than good. This may be so, but it is the surge of external origin which is most to be feared, and with a discharge type of arrestor on the line side of the choking coil, the increase of surge amplitude which occurs at this point due to reflection tends to accelerate the functioning of the arrestor.

12. **The Ferranti surge absorber.**—The "*Discharge*" type of arrestor absorbs the energy of the surge in a path parallel to the apparatus to be protected, and, as explained above, this involves connecting the line to earth, which is a disadvantage.

The "*Absorption*" type, of which the design made by Ferranti, Ltd., is the best known, is superior to the discharge type in that it is connected in the same way as a choking coil in series with the apparatus to be protected, and requires no earth connection to the line.

The device consists essentially of an air-cored inductance, adjacent to which but *insulated therefrom* is a sheet of steel. This sheet is termed the *energy dissipator* and is connected to earth. The voltage drop and energy loss in the absorber at 50 cycles are negligible.

In one form of construction the coil is of helical shape, and the energy dissipator is a cylinder surrounding the coil and forming the case of the absorber. This arrangement is indicated diagrammatically in Fig. 17.

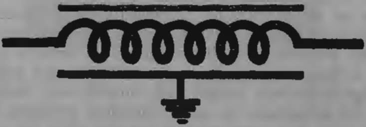


Fig. 17.

In an alternative form of construction, the coil, instead of being cylindrical, consists of two or more disc or flat spiral-wound sections contained between two flat sheets of metal forming the energy dissipator (*see* Pl. **51**).

The coil acts as the primary of an air-cored transformer, and the dissipator as a short-circuited single-turn secondary, in which eddy currents are induced by change of current in the primary, these currents being negligible at the supply frequency but extremely high at frequencies of 20,000 and

PLATE 51. FERRANTI SURGE ABSORBER.

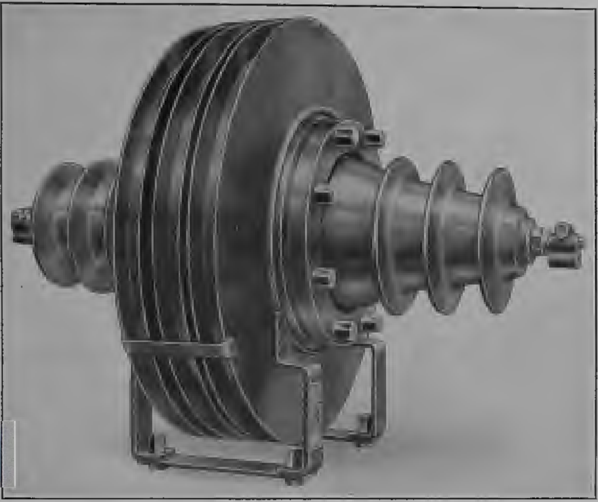


Fig. 1.—General View of Complete Apparatus.

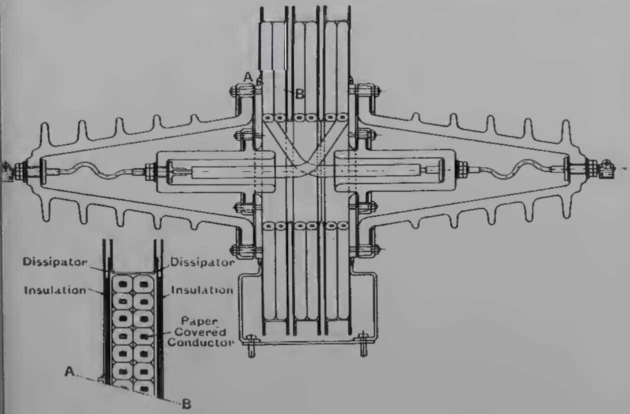


Fig. 2.—Cross Section of Absorber.

[*Permission of Ferranti, Ltd.*

upwards, or with the equivalent steep-fronted waves. The design therefore provides for the absorption of the energy of the surge in the " dissipator," the thermal capacity of which is ample for the worst surge likely to be experienced. Moreover, there is a large capacitance between the coil and the dissipator.

The apparatus therefore comprises, in effect—

(*a*) A choking coil, shunted by a resistance of high thermal capacity.

(*b*) A condenser between line and earth.

It therefore possesses the advantages of the condenser and choking coil pointed out above, and in addition tends to damp out the surge by absorbing its energy.

Pl. 51, Fig. 1, shows a design for 11,000 volts working voltage, and Fig. 2 shows a cross-section.

The overall dimensions of a 11,000-volts 30-amps. absorber are 25 inches diameter, 33 inches long, and the weight 200 lbs. Three such absorbers are required for a 3-phase system.

Based upon laboratory tests, the manufacturers claim that the absorption type of arrestor reduces the amplitude of high-frequency surges by 85 per cent., whereas the best discharge type arrestor can effect a 30-per-cent. reduction only. It is difficult to say whether these comparative figures still hold under practical operating conditions, but it is generally agreed that the Ferranti design of absorber is the best lightning arrestor yet devised.

It is, however, very costly, and its expense can only be justified in special circumstances.

13. **Connections of various lightning protection apparatus.**—Fig. 18 shows diagrammatically how the various devices referred to above are connected, one line only being given.

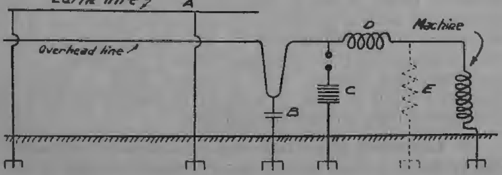


Fig. 18.

A is the overhead earthed wire, B a condenser, C a discharge arrestor, D is a choking coil or absorption arrestor, and E an earthing resistance which is required if the machine neutral is not earthed. The arrestors B, C, and D are generally installed outdoors, but indoor types can be obtained. It is not intended to convey that all these types should be used together, but the only objection is that of expense.

14. **General remarks on lightning protection of H.V. lines.**—The subject of lightning protection does not lend itself to hard-and-fast rules, for location and conditions determine the best practice.

Statistics show that a large percentage of the surges occur on limited sections of overhead lines, which suggests that if bad areas could be determined before the construction of the line, the route might possibly be changed to avoid them. It is fairly well established also that the amplitude of a surge is considerably reduced after travelling a few miles along the line, and it may therefore be practicable to install insulators of much higher grade than is necessary from a supply voltage point of view, on a mile or two of the exposed portion of the line.

The modern tendency, however, is to concentrate on the protection of machinery and apparatus rather than upon the line itself, and it has been suggested that if the insulators on the first few poles at each end of the line are of lower grade than those on the rest of the line, this will invite flashovers which will tend to relieve the station apparatus and machinery. These flashovers will generally cause the leakage or overload devices to function, but a momentary interruption of supply is relatively unimportant compared with the damage to machinery which might otherwise occur.

Overhead systems particularly exposed to thunderstorms abroad may require special treatment in places abroad, but, generally speaking, a sufficiently high factor of safety can be realized in Great Britain by running an overhead earthed wire, earthing the neutral point and reinforcing the insulation of 5 to 10 per cent. of the end turns of the H.V. transformer windings. This reinforcement of insulation cannot be carried out in generators and motors, and, therefore, from a lightning-protection point of view, it is better to connect all machines to overhead lines through transformers.

15. **Lightning protection on L.V. and M.V. systems.**—The problem is much simpler in L.V. and M.V. than in H.V. systems. In the former the lines are not generally in such exposed situations, the conductors are not erected so high above the ground, their potential is normally much nearer to that of the earth and the insulators flash over at a much lower voltage. Moreover, L.V. windings are much shorter and more distributed, and having, therefore, a much smaller impedance are not so liable to puncture as H.V. windings.

Further, when discharge types of arrestor are used the suppression of the power surge is a relatively easy matter.

L.V. and M.V. systems to which consumers' premises are connected, must be provided with lightning arrestors. Unless the system is very extensive, it will be sufficient to place the arrestors at the sub-station end of the lines, but choking coils may be placed at the leading-in points to consumers' premises if thought desirable, though they are not really necessary (*see* Sec. 57).

Pl. 48, Fig. 2, shows a simple type of discharge arrestor suitable for A.C. or D.C. lines up to 650 volts.

Referring to the inside view, the left-hand lead connects the line to a dished copper disc which, being under the porcelain insulating it from the containing case, is not visible in the illustration.

This disc is insulated from a metal plate forming one terminal of a large block of carborundum (the limiting resistance) by sheets of perforated mica. An air gap is thus formed between the line and the carborundum block which is connected to earth by the other lead. The air gap is adjusted by varying the thickness of the mica sheets to break down at about 2,000 volts.

The apparatus is contained in a dust and weather-proof case of galvanized iron which can readily be opened for inspection. The arrestor proper is completely insulated from the case by means of porcelain.

For W.D. purposes, the installation of lightning protection is governed by D.W. Technical Instructions No. 261, 1930.

26. *Conversion from A.C. to D.C.*

1. Conversion from A.C. to D.C. will never be undertaken unless it is entirely unavoidable. Converting plant has several disadvantages when compared with static transformers—greater first cost, increased maintenance and supervision charges, and a bigger power bill owing to its lower efficiency; whereas a 100**kVA** static transformer has an efficiency varying from 94 per cent. at quarter load to 98 per cent. at full load; the most efficient form of converting plant, the rotary convertor, of similar capacity, reaches an efficiency of only 85 per cent. at quarter load and 90 per cent. at full load. The cost of this power loss is much greater than is usually appreciated, since plant normally runs moderately loaded for long periods.

2. The available types of converting plant will be considered under three heads, according to the D.C. output required:

i. 50*kW and over.*—Such outputs will usually be needed for feeding existing D.C. power and lighting systems or for charging large station batteries.

A case in which conversion may be advisable for economic reasons is that of a workshop fitted throughout with D.C. motors and its own D.C. generating plant. If an A.C. supply is available, it may be desirable to dispose of the generating plant, and convert the A.C. supply to D.C. so that the existing motors and wiring may continue to be utilized.

ii. 1 *to* 50*kW*.—Supply to searchlights, cinema equipment, and X-ray and other medical apparatus.

iii. *Under* 1*kW*.—Supply to wireless transmitting and receiving sets, and the charging of portable batteries.

3. 50*kW and over*.—The following types of plant are available :—

i. Motor generators.
ii. Rotary convertors.
iii. Motor convertors.
iv. Mercury arc rectifiers.

The first is the simplest type and consists of two distinct machines, an A.C. synchronous or induction motor—usually the latter—and a D.C. generator, mechanically coupled together on one bedplate.

A rotary convertor may be considered as an ordinary D.C. generator with slip-rings provided at one end of the armature, in addition to the commutator at the other. The ratio of the A.C. to D.C. voltage being constant, a static transformer is usually necessary with this machine, and in the comparisons which follow will be treated as part of it.

A motor convertor is intermediate between an induction motor generator and a rotary convertor. It consists of an induction motor and a D.C. generator, mechanically coupled together on one bedplate, but with the rotor of the induction motor and the armature of the D.C. machine electrically coupled as well. Part of the power is transmitted from one machine to the other mechanically, and the remainder electrically.

Mercury arc rectifiers depend for their action upon the fact that whereas a voltage of about 20 is sufficient to pass a current through mercury vapour at a low pressure from a cool iron or carbon anode (positive electrode) to a hot mercury cathode, several thousands of volts are necessary at normal temperatures to pass current in the opposite direction.

Two types of equipment are available : iron-clad and glass-bulb rectifiers ; but as the former are only made in sizes too large for military requirements, glass-bulb plant alone will be further considered.

A mercury arc rectifier consists essentially of a highly-exhausted glass bulb with several dog-leg arms. At the end of each arm is a carbon anode, and at the bottom of the bulb is a pool of mercury—the cathode. These anodes are fed from a transformer, whose primary is in the A.C. supply circuit, and the direct current is taken from the mercury pool cathode and the neutral point of this transformer.

Auxiliary apparatus consists of a relay and auxiliary electrodes for starting and light-load running, and a fan for cooling; the whole plant, including the transformer in sizes up to **25kW**, being compactly contained in a cubicle about 4 feet × 2 feet 6 inches × 7 feet high. The main loss is due to the constant voltage drop in the arc, and consequently mercury arc rectifiers are most efficient at high voltages, but nearly equally efficient at all loads. They are not recommended for searchlight operation owing to this poor efficiency at the voltages required by searchlights.

4. The relative advantages and disadvantages of these machines for loads of **50kW** and over will now be discussed.

i. *First cost.*—The rotary convertor, including the transformer, is normally about 10 per cent. cheaper than the motor convertor, mercury arc rectifier or motor generator, which cost about the same. The necessary switchgear in each case is included in this estimate.

ii. *Starting.*—Mercury arc rectifiers are started by pressing a push, and induction motor generators, of course, in the same way as ordinary induction motors. Rotary convertors and motor convertors require a little skill, particularly the former.

iii. *Operation.*—Synchronous machines are not so stable in operation as asynchronous ones, but rotaries have been much improved in this respect of late. In a large sub-station it is advisable to have some plant of each kind, as with synchronous plant only, starting up again after a complete shut down is very difficult, owing to the fact that the D.C. voltage has to be at nearly its normal value at the moment of switching in. The result is a considerable momentary overload and surges, which may throw synchronous machines out of step again. Rotary convertors and motor convertors have higher overload capacities than mercury arc rectifiers. Automatic and remote operation is possible with all types of plant, but simplest and cheapest with mercury arc rectifiers.

iv. *Maintenance cost* is highest with rotary convertors, mainly owing to brush renewals and commutator and slip-ring wear; and least with mercury arc rectifiers. Bulbs should last several thousand hours before burning out.

v. *Efficiency.*—At full load in the case of **100kW** plant, the rotary convertor has an efficiency of about 90 per cent., mercury arc rectifier (at 460 volts) 90 per cent., motor convertor 88 per cent., and motor generator 80 to 82 per cent. At lower loads the mercury arc rectifier has the advantage.

It should be emphasized in this connection that the important consideration is the average efficiency with fluctuating loads over long periods.

vi. *Power factor.*—The rotary convertor, motor convertor, and synchronous motor generator may all be designed to have a power factor approaching unity for all loads from one quarter full load upwards. The mercury arc rectifier will have a power factor of about 0·93, while the power factor of an induction motor generator of moderate capacity will vary from 0·85 at full load to 0·7 at half load.

vii. *Voltage variation.*—As a motor generator consists of two separate machines, any range of voltage variation required can be catered for in the design. Without special apparatus, and simply by adjusting the field excitation 40 per cent. variation can be provided with motor convertors, but only 10 per cent. to 15 per cent. with rotary convertors. Voltage variation with mercury arc rectifiers is arranged for by variable tappings on the supply transformer, and here again 10 to 15 per cent. is usual. For all ordinary purposes this range is sufficient.

viii. *Cost of building and foundations.*—Mercury arc rectifiers require no foundations beyond a 3-inch concrete floor, and the space occupied by them and their necessary switchgear is less than with rotating machinery. Consequently the first cost of mercury arc rectifier sub-stations is low.

5. *Type to install.*—For loads of **50kW** and over the induction motor generator is at a great disadvantage, owing to its low efficiency and power factor, and for military purposes the simplicity of operation of mercury arc rectifiers is valuable. The choice between mercury arc rectifiers, motor convertors, and rotary convertors will usually be made on the comparative prices (including buildings, maintenance, and cost of power supply), the personnel available, and the views of the officer concerned.

6. *Under* 50*kW*.—Motor convertors cannot be obtained for smaller outputs than 50kW, and rotary convertors are expensive and have few advantages over induction motor generators. The choice lies between induction motor generators and mercury arc rectifiers, the advantage probably being with the former. If, however, new plant is being installed and the supply cables are already well loaded, it may be necessary to take advantage of the high power factor of mercury arc rectifiers.

7. *Under* 1*kW*.—A great many different principles have been utilized with satisfactory results for the rectification of small amounts of power, generally at low voltages. Some of the types of apparatus in use are briefly described below :—

i. *Thermionic rectifiers*, depending on some modification of the two electrode valve principle discovered by Fleming. The Tungar rectifier is a useful example, and can be obtained to give a D.C. output of 12 amperes or more at 75 volts from a 115 or 230-volt A.C. supply. A charging set with an output of 2 amperes, to charge 6 cells, measures 10″ × 6½″ × 7½″, and weighs 15 lbs.

ii. *Mechanical rectifiers*.—A method of conversion, which to a certain extent has been superseded by valve and copper oxide rectifiers, is that of a commutator driven synchronously by a small motor. The method is cheap and efficient, and is used for battery charging and X-ray apparatus. The main difficulty is the reduction of the effects of sparking.

If a mercury jet break be driven by a synchronous motor, the break may be used as a rectifier. Such an apparatus may be used with induction coils requiring 20 amperes at 200 volts, and also for giving charging currents up to 5 amperes.

iii. *Copper oxide rectifiers*.—A recently developed device for rectifying A.C. depends for its action upon the fact that the contact resistance between copper and a copper oxide coating is about one thousand times as great when the current is passing from the copper to the oxide as it is when the current is passing in the reverse direction. The basis of the unit junction is a copper washer with one side oxidized, and numbers of these units may be arranged in series or parallel to obtain any voltage or current required. By bridge methods of connection, full-wave rectification is obtainable.

Copper oxide rectifiers are, so far, used mainly for battery charging and electro-chemical work. They are the simplest and most robust form of apparatus possible, and self-contained cubicles to give 80 to 100 volts, 15 amperes, from any M.V. or L.V. A.C. supply are a standard article of manufacture. Their first cost is high when compared with motor generators, and the efficiency of a complete battery-charging equipment about the same at full load, *i.e.*, 50 or 60 per cent. At low loads copper oxide rectifiers maintain a relatively high efficiency.

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CHAPTER IV.

DISTRIBUTION.

27. *Principles of distribution.*

1. The subjects of generation and transmission of electrical energy having been dealt with in Chaps. I, II, and III, it is now necessary to discuss the subject of **distribution,** *i.e.*, the conveyance of the energy from the point at which it is generated, *or* the point to which it is transmitted at high voltage and stepped-down, to the various consuming devices where it is to be utilized.

This subject of distribution is of very great importance to the engineer, inasmuch as the cost of the necessary cables, whether underground or overhead, amounts in most schemes to a large proportion of the total capital outlay.

2. There are two possible methods of distribution, viz. :—*series distribution* or distribution at constant current, and *parallel distribution* or distribution at constant voltage. The former has only a few applications in practice in the field of distribution pure and simple, such as groups of comparatively low candle-power lamps on a high-voltage circuit, *e.g.*, in trams, trains, &c., though there are cases in which it is used for the transmission of energy. If it were used for even a moderate number of lamps, quite high voltage would be involved, and the difficulties of insulation would become too great.

3. Whether A.C. or D.C. should be employed will usually have to be worked out from the point of view of economy, taking into consideration the nature of the load to be supplied, the amount of power required, the distance of the consuming area from the point of generation, and the cost of the transmission cables, with which must be reckoned the actual distribution feeders (*see* Sec. **28**).

Very few cases are likely to occur where D.C. is absolutely necessary for military purposes, the principal being for focus arc lamps (chiefly searchlights), X-ray and other medical apparatus, mobile workshops, and secondary batteries; so, when once the economic limits of D.C. distribution are exceeded and H.V. A.C. transmission becomes necessary, A.C. should be adopted for the L.V. distribution system. Otherwise the use of costly and inefficient converting machinery, requiring constant attention, will be required.

Thus, except in the case of small isolated systems, it is probable that A.C. will be employed, but the details and calculations for D.C. will be discussed first, and the modifications necessary for A.C. evolved therefrom.

4. The aim of the engineer must be to keep the voltage as nearly as possible constant over his area of supply under all conditions of load. It is obvious that *some* loss of voltage must occur, since all electrical conductors have some resistance ; the effects of this loss are :—

i. All consuming devices must receive a lower voltage than that generated at the source of supply.
ii. Some consuming devices may receive a lower voltage than others.
iii. The voltage at the consuming points will vary as the power being taken in the vicinity varies (*i.e.*, as lamps, &c., are switched on or off).

Effect (i) need not be harmful ; it merely necessitates generating at a higher voltage than the declared voltage at the consuming points ; it is in fact a commercial necessity, and does not necessarily involve any differences in the voltages of the consuming devices if the circuits be properly arranged.

Effects (ii) and (iii), however, involve *variations* of voltage, which, particularly in the case of lamps, are very objectionable if not kept within bounds and are harder to overcome.

The ideal design would be for each lamp, &c., to have its own conductors, so proportioned, according to the current taken and its distance from the source of supply, that the voltage at each lamp, &c., would be the same. This is clearly a counsel of perfection impossible to realize, but the plan can be carried out to a certain extent by taking the subdivision of the conductors as near as possible to the lamps.

5. In practice the energy is taken from the generating station or sub-station to various points, known as **feeding points,** by the **feeders ;** from the feeding points it is further distributed by **distributors ;** finally **services** carry it into the various buildings.

The whole system is known as the *network,* and the point it is desirable to arrive at in designing a conductor network is to obtain the *maximum uniformity of voltage combined with the minimum weight of copper,* and thus keep the capital costs as low as possible consistent with good voltage regulation.

The latter is ensured by the regulation of the Electricity Commissioners concerning the declared voltage at the consumer's terminals, which is as follows :—

> . . . . The voltage so declared shall be constantly maintained, subject to a variation not exceeding 4 per cent. above or below the declared voltage. . . .

This amount of variation is unobjectionable, and in practice, in a well-designed system, the variation is usually less than ± 4 per cent. Consequently, the main object will be to reduce the capital cost and maintenance charges to a minimum.

As has been pointed out in para. 4, there must be some voltage drop, and two problems at once present themselves, viz. :—

i. What voltage drop is to be assumed in working out the sizes of the various conductors ?
ii. How is this loss to be divided amongst the various positions of the network ?

Consider (ii) first. The total drop has to be distributed over feeders, distributors, services, and house wiring, and of these conductors the feeders will probably be the longest. But it is customary to run small wires, known as **pilot wires**, back from the feeding point to a voltmeter at the station, so that the switchboard attendant can at any time ascertain the actual voltage at the feeding points, and it is his duty to maintain this voltage at an approximately constant figure. Beyond the feeding points he has no real control. Consequently, the voltage drops in the feeders may be relatively large, whereas those in the distributors and services must be small if the voltage regulation is to be good. It is virtually the question of voltage regulation which determines the proportion of the total loss to be borne by the various portions of the system.

Assumptions have to be made by the light of experience, and the figures given in the following table can be taken as a good general guide for D.C. systems *supplied direct from a power station* :—

Maximum permissible voltage drop.

Conductor.	General case.	Special case.
	Per cent.	Per cent.
Main feeders	7·0	9·5
Branch feeders	0·5	1·0
Main distributors	1·5	1·5
Branch distributors	0·5	0·5
Service lines	0·5	0·5
Total loss	10·0	13·0

The existence of two sets of figures calls for some explanation. It will frequently happen in a distribution scheme that one feeder is longer or much more heavily loaded than the others, and to confine the voltage drops in this feeder to the same amount as those in the others would entail a prohibitively heavy cross-section of copper. In such a case it is usual to allow a heavier drop in the very long feeder and to deal with this by running at a higher voltage on this feeder in the central station, employing a separate set of bus-bars kept at a higher voltage than the general bars; this may be achieved in various ways, and is perhaps most commonly effected by means of a **series booster,** arranged to compensate for the extra drop. In some cases, of course, it may be advisable to connect more than one feeder to the boosted bus-bars.

It should be noted that in both the general and the special case, in comparison with the feeder losses, the other losses are small.

6. **Current-carrying capacity of conductor.**—Although the permissible drop in voltage will, in the majority of cases, determine the size of conductor to be selected, yet there may be instances, *e.g.*, a very short line, in which the permissible rise in temperature is the ruling factor, and care must be taken that the safe current is not exceeded.

The safe current-carrying capacities of cables are given in Appendices VI and VII. The figures in Appendix VI may be taken for cables laid in pipes or ducts, and Appendix VII for cables laid direct in the ground. (*See also* Sec. **37**.)

28. *The feeder system.*

1. The first point to be considered in the design of a network is the **position of the feeding point** or points. These will normally be the natural load centres of the areas to be supplied, and, except where these areas are isolated and some distance apart, it may safely be assumed that the feeding points will be linked together by the distributors as shown in Fig. 19.

As will be explained in the next section, the position of the feeding point with reference to any particular distributor is a factor of considerable importance in so far as the sectional area of that distributor is concerned, and great care should be taken in the selection of feeding-point positions. In the very simplest cases, assuming that the routes of the distributors are more or less fixed, it would be possible to work out mathematically and exactly how many feeding points would be required and where they would be best situated; but there is no general solution that is applicable, and, generally speaking, the number and positions of the feeding points can best be determined by a close study of the network.

In the case of a big area, it should be possible so to arrange the feeders that they fall into groups, according to their lengths and loads, and connect each group to separate bus-bars with separate regulation. Unless this is done, it may not be possible to maintain the voltage of supply at all the consuming points within the desired limits.

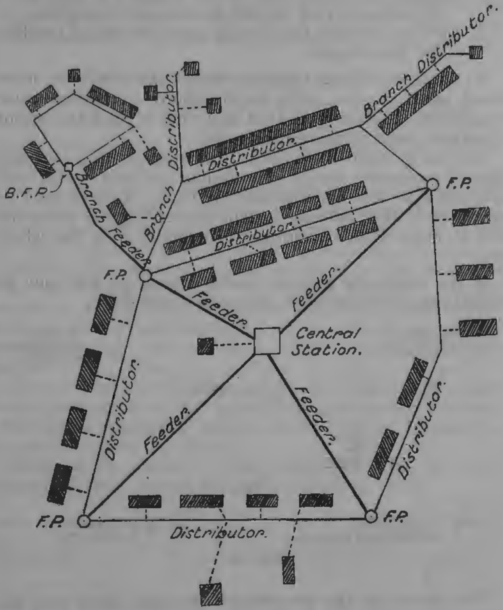


Fig. 19.

If one feeder is occasionally very heavily loaded whilst the others are on normal load, and all are connected to the same bus-bars, perfect regulation of the whole system is impossible. But it is more than probable that such a peak load would only occur at certain hours or seasons, and the difficulty would be met by connecting that particular feeder to auxiliary bus-bars at a higher voltage.

It should be noted that *no current should be tapped from the feeders* at any point because such supplies would be subject to undesirably large variations of voltage.

2. Before it is possible to calculate the section of copper required for a feeder, it is, of course, necessary to know the full-load current, and here it may be noted that systems of distribution may be subdivided as follows :—

i. Systems in which each feeder supplies a number of distributors that are fed from no other source.

ii. Systems in which the feeding points are linked together by distributors.

In the case of (i) the full-load current can readily be determined, but in the case of (ii) the distributor calculations must be made first, in order to find out how much of the total current comes from each of the feeding points.

System (i) might be decided upon where, with a centrally situated generating station, the various portions of the load, each more or less concentrated in itself, are scattered as regards each other, whereas system (ii) would apply where the load is more or less uniformly distributed over the whole area.

3. An imaginary example under system (i) will now be worked out in order to show the general procedure.

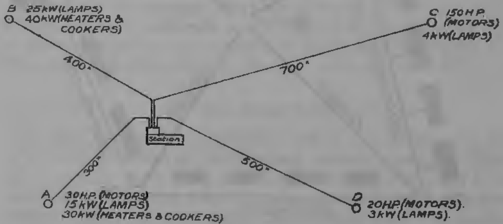


Fig. 20.

For system (ii) the procedure is the same when once the amount of current supplied from each feeding point has been determined (*see* Sec. **29**, paras. 3 *et seq.*).

Fig. 20 shows the maximum load allowing for *Diversity-Factor* at each of four feeding points, A, B, C, and D. (In all these distribution diagrams, single lines represent both the *out* and *return* conductors.)

The distribution beyond the feeding points is not shown and does not affect the example.

Assume a declared voltage of 230, a voltage drop of 10 per cent., and an average motor efficiency of 75 per cent.

The calculations involved are shown in Table **C.** It will be noted that the feeder C is abnormally large, and the circumstances really demand a higher working voltage, or alternatively, a series booster. If the voltage were doubled only one-quarter the size of cable would be required, and in practice the three-wire system would be used, the motors being fed at 460 volts. (*See* Sec. **31**.)

The sizes selected in column XI are based on voltage-drop considerations. For very short feeders the size may sometimes be determined by current-carrying capacity. (*See* Sec. **27**.)

29. *The distributor system.*

1. Beyond the feeding points comes an area which is beyond the ken of the man at the switchboard, where *the possible losses have to be reduced to a minimum*, or bad voltage regulation will result.

2. To calculate a **distributor fed at one point only** presents no difficulties; the point furthest from the feeding point is clearly the point of lowest voltage, and to ascertain the drop to this point it is only necessary to summate the products of the currents and the resistances of the conductor from the feeding point to the various tappings, whether services or sub-distributors. Moreover, since it will usually be advisable for each distributor to be of the same sectional area throughout, the resistances will be proportional to the lengths.

The *position* of the feeding point in the distributor is, however, an important factor. Unless care is taken in its selection, a prohibitive amount of copper will be required to keep the drop within reasonable limits.

Suppose, for instance, a distributor 400 yards long with tappings of 100A at each 100 yards, thus (Fig. 21) :—

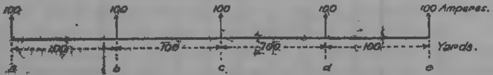


Fig. 21.

Also suppose this distributor is fed at the point *a*; then *e* will obviously be the point of lowest voltage, and the drop from *a* will be :—

$$\{(100 \times 100) + (100 \times 200) + (100 \times 300) + (100 \times 400)\} \times r = 100{,}000r,$$

where *r* is the resistance of one yard of *double* conductor.

Now suppose the distributor to be fed at the point *c*; then points *a* and *e* will each be points of lowest voltage, and the drop from *c* in each case will be :—

$$\{(100 \times 100) + (100 \times 200)\} \times r = 30{,}000r,$$

TABLE C—*Calculation of feeders.*

Feeders.	Distance in yards.	Connections.			Total load (motors at 75 per cent. efficiency). kW.	Total amperes at declared voltage of 230V.	Drop in volts in feeder.	Resce. in ohms per feeder = VIII/VII.	Resce. in ohms per 1,000 yards.	Smallest conductor (Appendix VI) limited by V.D.
		Lamps. kW.	Heaters and cookers. kW.	Motors. B.H.P.						
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
										Sq. in.
A	300	15	30	30	75	326	23	0·07	0·118	0·25
B	400	25	40	—	65	283	23	0·085	0·106	0·25
C	700	4	—	150	154	670	23	0·034	0·025	1·00
D	500	3	—	20	23	100	23	0·23	0·23	0·10

or, for the same voltage regulation, r in the second case can be $3\frac{1}{3}$ times as great as in the first case, *i.e.*, the conductor can be $\frac{3}{10}$ the sectional area.

In an unevenly loaded distributor it will be advantageous to feed at or near the point of densest load; no definite rule can be laid down, however, and each case must be decided on its merits. Even if a longer feeder is necessitated, good regulation is of such importance that the extra cost will generally be justified, but, of course, it must be remembered that there is usually more than one distributor to be considered.

3. Where the **distributor is fed from more than one point**, however, or where there is a more or less complicated network of distributors, the problem is not quite so simple. The best way to solve it is to *assume* a point, or points, of lowest voltage, and to suppose that the conductors are actually cut at that point so that a portion, x, of the current supplied at that point is fed from one direction, the remainder coming by the alternative route. Then by the simple process of equating the drops by the two alternative routes the value of x can be found. If by any chance x should prove to be negative, it will merely mean that the cutting point chosen is not the point of lowest voltage; substitution for x, however, in the line diagram, having due regard to sign, will soon indicate which *is* the point of lowest voltage and what is the actual value of the current in each portion of the distributor.

For the more complicated networks, more than one cutting point will have to be assumed, and there will be more than one unknown, but sufficient equations for a complete solution will always be obtainable.

4. To illustrate the method of working, it will be best to take imaginary examples and work them out in detail.

Consider, first, a simple case of a **distributor fed from the two ends,** A and B, which are at approximately the same potential, and suppose that tappings are taken at the points *a*, *b*, *c*, *d*, *e*, and *f*. The current taken at each point and the distance of each point from the feeding points are indicated in Fig. 22.

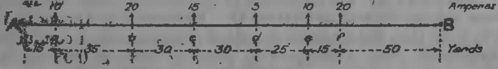


Fig. 22.

Suppose that the maximum permissible drop to the point of lowest voltage is 4V.

Select any point, say *d*, and assume that the conductors are cut at that point.

Suppose that, of the 5A supplied at *d*, *x*A comes from A. so that $(5 - x)$A comes from B.

The current flowing in the different portions of the circuit will then be as indicated in Fig. 23.

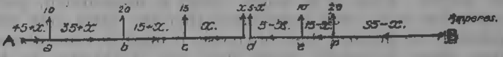


Fig. 23.

But, by assumption, the difference of potential between A and *d* is equal to the difference of potential between B and *d*.

Therefore, the sum of the voltage drops on the two sides must be equal.

Also conductor resistances are proportional to distances.

$\therefore x \times 30 + (15 + x) \times 30 + (35 + x) \times 35 + (45 + x) \times 15 = 110\ x + 2{,}350 = (5 - x)\ \times 25 + (15 - x) \times 15 + (35 - x) \times 50 = 2{,}100 - 90\ x,$

whence $x = -1{\cdot}25$A.

Substituting this value for *x* in Fig. 23 it is found that the actual current flowing in each portion will be as shown in Fig. 24.

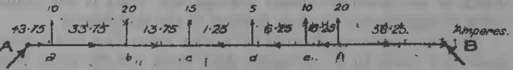


Fig. 24.

From this it will be clear that *c*, *not d*, is actually the point of lowest voltage, and that the currents fed to the distributor at A and B are 43·75A and 36·25A respectively.

Let *r* be the resistance of one yard of double conductor. Then, since V = IR,

$$4 = \{(43{\cdot}75 \times 15) + (33{\cdot}75 \times 35) + (13{\cdot}75 \times 30)\} \times r,$$

whence $r = 0{\cdot}00178$ **O**.

That is to say, the resistance of one yard of single conductor must not be more than 0·00089 **O**. Reference to Appendix VI will show that the smallest standard cross-section of conductor permissible *from a voltage-drop point of view* is 0·03 sq. in. which has a resistance of 0·8468 ohm per 1,000 yards.

Before this cable is definitely selected, however, it must be ascertained whether it is capable of carrying the current safely. In this particular case the maximum current, *i.e.*, 43·75A, is well within the safe carrying capacity (71A for a twin paper-insulated lead-covered cable laid in a duct), but with very short cables or with a high permissible drop it might not so happen.

5. The case of a **ring distributor,** fed at one point only, can be worked out in precisely the same way, the only difference being that A and B are one and the same point.

6. **Double-ring distributors** may at first sight appear to present greater difficulties, but they, and in fact any form of network, can be calculated by the *cutting-point* method. More than one cutting point will have to be chosen, and it will be found necessary so to select these that there is only one path by which each load current, except those at the actual cutting points, can be supplied from the feeding point or points, *i.e.*, each mesh must be opened so that only the loads at the cutting points can be supplied by two routes.

7. As an example, consider the double-ring distributor indicated in Fig. 25 which is fed at one point A.

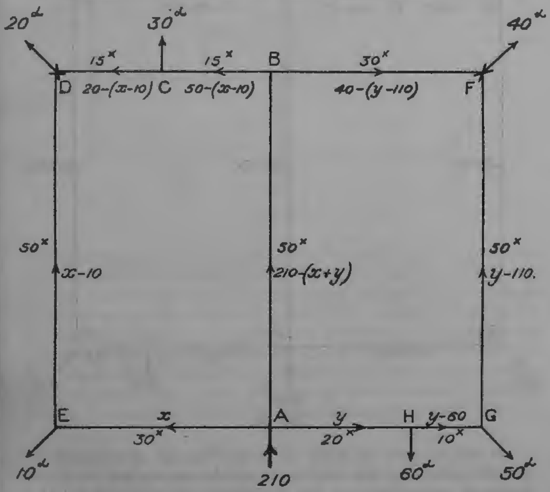


Fig. 25.

In this case it will be necessary to assume two cutting points. Assume that D and F are chosen, and that the currents flowing from A towards E and H are *x*A and *y*A respectively.

The total current fed at the point A is obviously 210A, and the currents flowing in each section can be inserted in terms of x and y as shown. Then, by assumption, the drop from A to D *via* E is equal to the drop from A to D *via* B and C. Also the drops from A to F by the two alternative routes are equal.

$$\therefore x \times 30 + (x - 10) \times 50 = (30 - x) \times 15 + (60 - x) \times 15 + \{210 - (x + y)\} \times 50,$$

and $$y \times 20 + (y - 60) \times 10 + (y - 110) \times 50 = (150 - y) \times 30 + \{210 - (x + y)\} \times 50,$$

whence $$x = 39{\cdot}87, \text{ and } y = 119{\cdot}42.$$

Substituting these values for x and y, it is found that the actual currents flowing in each section are as shown in Fig. 26.

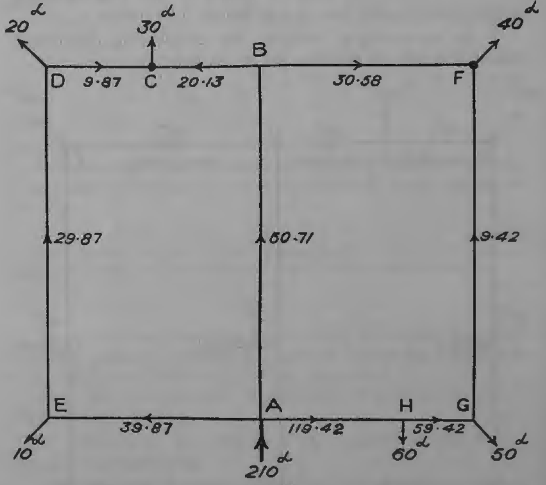


Fig. 26.

It will at once be seen, as in the case of distributors fed at both ends, that the cutting points chosen are not the actual points of lowest voltage, for the current in the section CD is flowing from D to C instead of from C to D.

The points C and F clearly prove to be the points of lowest voltage, and the current in each section is known, so the size of conductor for a given voltage drop can be calculated as before. It will be found, however, that the drop to F is greater than the drop to C in the proportion of approximately 5 to 4, and in all such cases care must be taken that the size of conductor be calculated from that portion of the system in which the biggest drop occurs. If this were not done, the permissible drop would be exceeded in a portion of the system.

8. In some instances it may be worth while to install a smaller conductor in a portion of the system, but no definite rule can be laid down. For example, if Fig. 27 represents a network approximately to scale, and all the conductors are of the same cross-section, then it will be found that E is the point at which the voltage is lowest when the system is fully loaded.

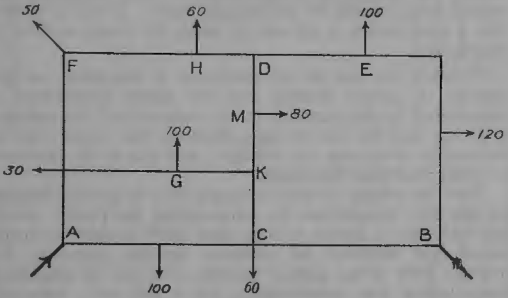


Fig. 27.

Theoretically a saving of about 7·4 per cent. of copper can be effected by providing the portions FD, DE, and MD with a cable that is half the sectional area of the rest of the system, but in practice this may not prove to be so, since there is not an unlimited number of cable sizes available. If an economy appears to be possible, all calculations must be repeated, and due allowances made for the smaller conductor when equating the voltage drops; for a complicated and extensive network it may be necessary to repeat the calculations several times.

30. *House services.*

The conductors which carry the energy from the distributing points into buildings are, as a rule, comparatively short. They are fed from one end only and have no tappings, and their calculations call for no particular comment.

It may be mentioned, however, that an undue variety in the sizes of cables to be employed should be avoided, and, therefore, the services should be grouped. Some may be considerably larger than actually required according to the voltage drop allowed, length, and load, but this will be cheaper than ordering a number of short lengths of cable.

31. *3-wire distribution.*

1. Hitherto distribution with two wires only has been considered, and in the example given in Sec. **28**, para. 3, the cost of the feeders alone would amount to about £2,500 for cables or about £1,000 for aerial lines. To this would have to be added the cost of the distributors and services.

It is obvious, therefore, that anything which will serve to reduce the amount of copper required, and, therefore, the capital outlay, would be an immense boon. It will be shown that a great saving is effected by using the 3-wire method of distribution.

2. Since the size of the conductor is dependent on the amount of current flowing, and the power transmitted is represented by the product of the current and the voltage, it is clear that the current (and, therefore, the copper) can be reduced by increasing the voltage ; and this is the direction in which relief must be sought.

Now the voltage at which a supply may be given is limited by the E.C. Regulations for safeguarding the public, which are such that a higher voltage than 250V cannot be introduced into buildings for ordinary lighting purposes. In practice 240V is the highest possible that can be employed when taking into consideration the 4 per cent. variation permitted by the Electricity Commissioners. 230 is now the British Standard consumer's lamp voltage.

If the supply is A.C., the desired saving of copper can be very easily effected, since the energy can be transmitted to the various load centres at high voltage and stepped down to the working voltage by means of static transformers.

With D.C., however, rotating machinery would be needed to effect such a reduction, quite apart from the difficulties of generating at high voltage, but the 3-wire system enables distribution to be made at double the lighting voltage and so saves a considerable amount of copper.

3. The principle upon which 3-wire systems are based will first of all be considered, and then the saving effected will be ascertained.

Suppose two entirely distinct but similar 2-wire circuits as shown in Fig. 28.

If the lamps happen to be distributed as shown, it is evident that they may be connected two in series, as shown in Fig. 29, in which case the two intermediate wires become unnecessary and may be omitted.

There are, however, obvious objections to such an arrangement. To begin with, it does not permit the use of a higher distribution voltage than 250V ; moreover, if one of the pair of lamps is for any reason extinguished, its companion in series with it must also be extinguished. A third wire, as shown in Fig. 30, is, therefore, extended from the junction of the generators.

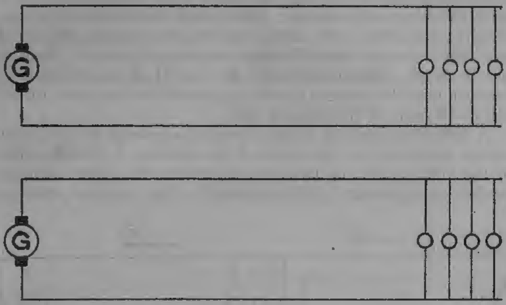


Fig. 28.

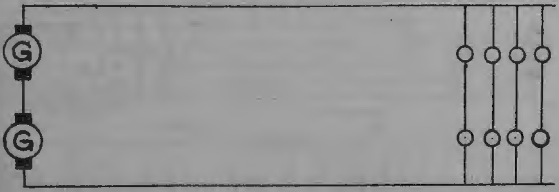


Fig. 29.

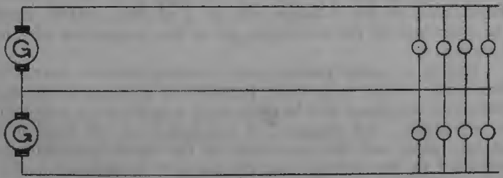


Fig. 30.

Ignoring for the moment the question of the 250V voltage limit, there would be clearly no necessity for this third or *neutral* wire if the two sides of the circuit were what is known as *balanced*, as shown in Fig. 30, where the neutral is not called upon to carry any current; but, when the amounts of the current on the two sides of the system are unequal, the third wire has to carry the difference between the two. Such a case is shown diagrammatically in Fig. 31, from which it is also seen that the current is not necessarily in the same direction in all parts of the neutral wire.

A difficulty that will at once become apparent is that, with uneven loads on the two sides of the system, it is impossible for the voltages on the two sides to remain the same without special arrangements; for instance, if the station voltage across the outers in Fig. 31 be 480V, and if the mid-wire be disconnected and the small drops in the mains be ignored, the voltage on the 5 lamps will be only $\frac{3}{8}$ of 480 = 180V, whilst that on the 3 lamps will be $\frac{5}{8}$ of 480 = 300V, since the resistance of the two sides are in the proportion of $\frac{1}{5}$ to $\frac{1}{3}$, or 3 to 5.

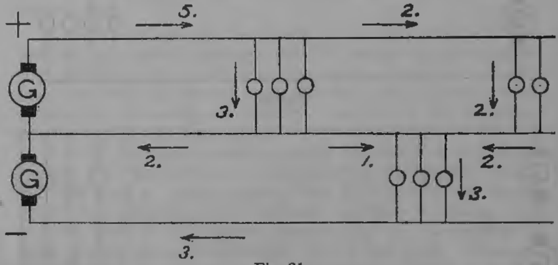


Fig. 31.

This is a rather heavier *out-of-balance* than is normally met with, except in isolated portions of a system, and the difference in voltage will be very much less when the mid-wire is connected. For instance, if the lamps are all connected at one point, and the resistances of the outers and mid-wire are all 1 O, the voltage distribution will be such as is diagrammatically represented in Fig. 32, *i.e.*, the lamp voltage on the positive side will be 233V, whilst that on the negative side will be 239V.

But, although this is an exaggerated instance, the facts that some uneven loading must necessarily occur and that it requires voltage regulation are such as cannot be neglected.

The special methods adopted to deal with such a situation are dealt with later (Sec. **32**).

The groups of lamps shown in Fig. 31 can be taken to represent loads in different buildings, and it will be seen that, provided the process of *balancing* the voltage on the two sides be accomplished, it will be possible to distribute at 480V, although current at 240V only is taken into the buildings. The mid wire must be earthed (see page 125).

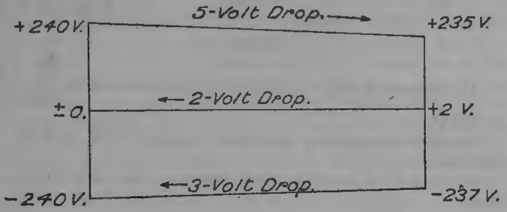


Fig. 32.

4. It now remains to be seen what **saving in copper** is effected by the utilization of the higher voltage.

Suppose that it is necessary to supply ten 230V 60W lamps, and that a 4 per cent. voltage drop is permitted in the mains.

The lamps may be supplied by a simple 2-wire system as in Fig. 33.

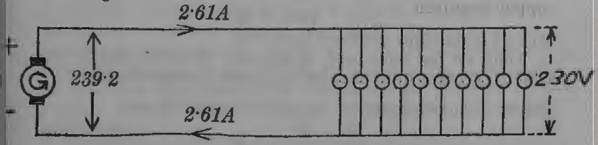


Fig. 33.

The current in the mains will be $\frac{60 \times 10}{230} = 2·61A$, and the voltage drop permitted $= 9·2V$ (*i.e.*, 4·6V in each main).

If R_2 = maximum resistance of each main in ohms,

then $R_2 = \frac{4·6}{2·61} = 1·76O$.

∴ **total weight of copper required** $= \frac{k}{1·76} + \frac{k}{1·76}$,

where k is a constant depending upon the length and resistivity of the conductor.

Now suppose that these same lamps are connected as in Fig. 34 :—

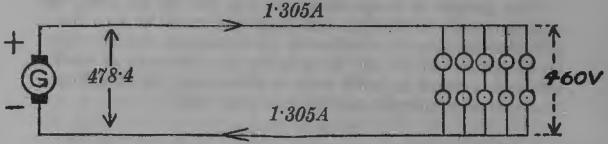


Fig. 34.

The current flowing in the mains in this case will be $\frac{60 \times 10}{230 \times 2}$ $= 1\cdot305$A.

But the voltage drop permitted is now 18·4V, or 9·2V in each main.

So that if $R_3 =$ maximum resistance of each outer in ohms,

then $R_3 = \frac{9\cdot2}{1\cdot305} = 7\cdot04\mathrm{O}$.

But a third wire has been shown to be necessary to deal with the possibility of uneven loads, and this third wire has to carry the difference in currents between the two sides of the system. It was formerly the practice to put in a mid-wire of half the cross-section of an outer, in which case **total weight of copper required** $= \frac{k}{7\cdot04} + \frac{k}{7\cdot04} + \frac{k}{14\cdot08}$, where k is the same constant as above.

Thus, for the same load, at the same distance, and for the same percentage drop in volts, *i.e.*, same voltage regulation,

weight of copper (2-wire) : weight of copper (3-wire)

$$= \frac{2k}{1\cdot76} : \frac{5k}{14\cdot08} = 16 : 5.$$

That is to say, nearly 70 per cent. of the copper is saved by the adoption of the 3-wire system of distribution, and this at once explains the almost universal use of the system for D.C. working (but *see* Sec. **33**).

As against this great advantage must be reckoned the following undoubted disadvantages :—

i. Extra machinery is entailed (*see* Sec. **32**).
ii. Three wires have to be laid, jointed, and maintained instead of two.
iii. The switchboard, instruments, and battery arrangements are rather more complex.

32. *Balancing on a 3-wire system.*

1. Great care should be exercised in the design and connections of a 3-wire system to ensure that the loads on the two sides are as nearly as possible balanced—in fact, the *installed out-of-balance* on the station should be practically nil. At the same time it must be remembered that *local* balancing is also necessary to prevent large currents flowing in sections of the neutral wire. It is no use connecting one group of barracks between positive and neutral and another group of barracks, having the same installed load, between negative and neutral, for it is more than likely that at times one of the groups of barracks will be unoccupied. Similarly, it is useless to balance two equally loaded buildings against one another when the buildings will be used at different times or are widely separated. In fact, every area and also large and occasional buildings, such as churches, theatres, or gymnasia, should receive a 3-wire supply, half the load being connected to the positive side of the system and half to the negative.

It is customary for supply companies to insist on a consumer taking a 3-wire service if his demand exceeds a certain amount, which amount varies according to circumstances.

2. For the same reason it is undesirable to install any motor, except the very smallest, on one side of the system. Even if, when running at full load, its current is well within the specified limit, the inevitable momentary rush of current on starting up will certainly make itself felt. Fortunately no difficulties are presented under this head; motors even down to small sizes are readily procurable for 480V, and they are, therefore, almost invariably *connected across the outers*, and do not affect the question of balance at all. In fact, from a power point of view, there is no necessity to use the 3-wire system.

The desirable limit in the size of the motor which may be permitted on one side of the system cannot be definitely laid down, as it must depend on load conditions. For small systems it might be necessary to impose a limit of ½ B.H.P., whereas on large systems this might be increased to 4 or 5 B.H.P.

3. Even if the balancing of the installed loads has been very carefully done, it is inevitable that there will at times be some *incidental out-of-balance*. This would mean disarrangement of the voltages, as has been shown, and consequent objectionable variations in the candle-power of lamps, so some steps must clearly be taken to deal with voltage disturbances.

The following methods are used :—

i. Two generators, generally on the same shaft and driven by the same prime mover.
ii. Static balancers.
iii. Motor-generator or balancer set.
iv. Floating battery.

4. The first method was common practice in the earlier days, and is still to be met with. The **two generators** are precisely similar, and at equal loads give equal voltages, the connections being as shown diagrammatically in Fig. 30. Any variations in loading are compensated for by adjustment of the field rheostats, so that constant attention by the man at the switchboard is needed. Moreover, two medium-sized machines cost more than one large one, so other methods are more generally adopted nowadays.

5. **Static balancing** is more particularly applicable to systems employing rotary converters or motor-converters. It is not strictly true to call it a method of balancing, since no boosting effect is produced by which the inequality of voltage lost in the line resistance due to an out-of-balance current can be neutralized, but it does compensate to a certain extent for unequal loading.

On a plain D.C. system it is necessary to provide, on the double-voltage generator supplying the outers, a mid-point by way of which the mid-wire current can return to the generator, and the simplest method of doing this is indicated in Fig. 35.

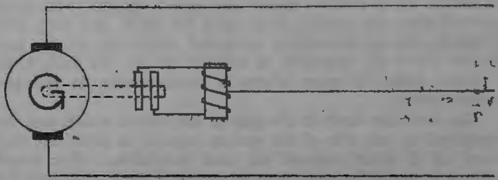


Fig. 35.

On the shaft of the generator are provided two slip-rings which are connected to two points of the armature winding, separated from each other by a pole pitch, the two points being, therefore, always at equal and opposite potential. Brushes on these slip-rings are connected to opposite ends of a choking coil, *i.e.*, a coil of large self-induction wound on an iron core, and the mid-wire is brought to the middle point of this coil. The reactance of the coil being high, only a small magnetizing alternating current will flow in it, but it offers a very small resistance to the passage of a direct current.

The middle point, to which the mid-wire is brought, will always be at a potential midway between that of the main brushes.

The current in the mid-wire has to make its way through the armature coils to whichever brush is connected to the more heavily loaded outer. Although the actual distance between the brushes and the tappings for the slip-rings is continually varying, and, consequently, the easiest path for the mid-wire current is now through one half of the choking coil and now through the other, yet the current will flow in practically equal strength to each slip-ring, because the impedance of the coil is sufficiently high to prevent it continually changing direction.

When the D.C. system is supplied by a rotary converter, the mid-wire is connected to the neutral point of the secondary of the step-down transformer, while with a motor-converter the connection is made to the star point of the rotor (A.C. side) ; no external choking coils are necessary in either case.

The operation of this balancing system depends on the out-of-balance voltage, and about 25 per cent. of the normal load is the heaviest out-of-balance current that can be dealt with effectively without a specially designed generator.

6. The **motor-generator,** although not so economical in first cost as a static balancer set, is more efficient in its balancing action, since, as will be explained, the voltages on the two sides can be maintained as nearly equal as desired, and it is consequently the most common form of balancing. It depends for its action upon the following well-known properties of a shunt machine :—

i. A shunt machine will run in the same direction as a generator or as a motor without changing its polarity.
ii. A shunt motor will increase in speed when the voltage across the armature is increased or when the field is weakened.

The main supply is obtained from double-voltage generators connected to the outers, whilst the balancer set, consisting of two small identical shunt-wound machines the armatures of which are mechanically coupled together, is connected, as shown in Fig. 36, with the fields cross-connected.

When the two sides are evenly loaded, and supposing that the fields are equally excited, the voltage will be equally divided between them, and they will revolve as motors, taking just sufficient power from the main bus-bars to supply the no-load losses.

But suppose that the load on the positive side is greater than that on the negative, as shown in Fig. 36; then the voltage would be unevenly distributed, the positive side being under-volted and the negative over-volted. Consequently, the field of machine B will be weakened and that of machine A strengthened. At the same time the voltage across the armature of machine B will be increased.

Both these results tend in the same direction, viz., to increase the speed of machine B; as the armatures of the two machines are rigidly coupled, the speed of machine A must also increase, and the back E.M.F. will rise to a figure equal to or in excess of the impressed volts. In the latter event machine A will become a generator, and will restore the deficient volts on the positive side at the expense of the surplus volts on the negative side. This tendency to generator action is, moreover, assisted by the fact that the field of machine A has been strengthened.

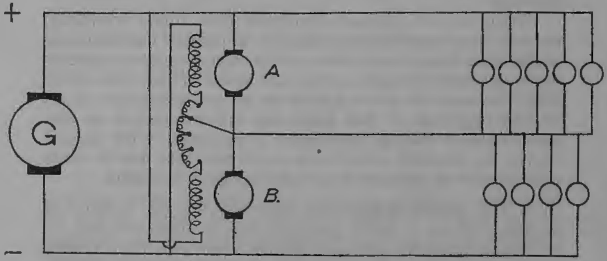


Fig. 36.

It will thus be seen that the balancing is very largely automatic, and it would be truly automatic were it not for the unavoidable losses in the machines themselves. For this reason an adjustable rheostat is provided as shown, and by its means the switchboard attendant can deal with any reasonable out-of-balance.

7. The **size of machine required** for balancers on any system must naturally depend on the amount of incidental out-of-balance anticipated, and this will depend largely upon the care exercised in dividing the various consumers between the two sides of the system.

It has been a common practice to install a balancer set capable of dealing with an out-of-balance of some 15 to 20 per cent. (expressed as a percentage of the current in the heavier-loaded side), but it is questionable if such large machines are justified; with reasonable care allowance for a 10 per cent. out-of-balance should be ample.

8. **Position of balancers.**—Consideration will show that the nearer the balancer set is to the unbalanced load with which it has to deal, the better, in theory, will be the conditions under which it has to work; the feeding points on the distributing networks will at once suggest themselves as suitable positions. Moreover, by placing a set at a feeding point, not only would the unequal drop in the feeder outers be avoided, but it would be possible to dispense entirely with the third wire in that feeder.

Where only one feeder is concerned, it might conceivably be feasible to install the balancer set at the feeding point, but normally such a course is not practicable, since running machinery is involved, and extra personnel and building accommodation would be necessary

With more than one feeder, balancers would be wanted at each and every feeding point, and it will be easily understood that it is unusual to find the balancers anywhere except at the generating station, where the space they occupy is of little moment and where they will always be under supervision of the engineering staff.

Moreover, where batteries are used in conjunction with the supply, it is common practice to combine the balancers with the boosters necessary for charging the two halves of the battery, *i.e.*, the balancers, in addition to balancing, are used as motors to drive the booster generators, the four armatures being arranged on the same shaft.

Experience has shown that this does not interfere with the primary function of the balancers, though, of course, it is necessary to install larger machines than would be the case if balancing were their sole duty.

During periods of light load, when the battery is doing all the work and no generators are running, it is not necessary to run the balancers, since the battery will maintain the balance sufficiently closely without them.

9. Where a battery is employed, it is in theory possible to dispense with balancers by keeping the **battery floating** across the outers, with its middle point connected to the mid-wire; but this means that the cells are very irregularly charged and discharged, and the resultant heavy depreciation prevents the adoption of this method.

33. *The calculation of conductors for a 3-wire system.*

1. To begin with, it is necessary to make assumptions as regards the amount of *incidental out-of-balance* likely to occur in the different portions of the system. This out-of-balance

is expressed as a percentage of the current in the more heavily loaded outer, and the amount anticipated will depend to some extent upon the care and thoroughness with which the wiring details have been divided.

For instance, suppose that the total load for which a 2-wire feeder has been calculated is 1,900A. If, say, a 10 per cent. out-of-balance is anticipated, this means that, under the worst possible conditions, there will be 950A flowing in, say, the positive outer, 95A in the mid-wire, and 855A in the negative outer. It is presumed that the installed loads were as nearly as possible balanced, so that there cannot be more than 950A in either of the outers under any conditions.

As a guide to the assumptions that may reasonably be made, the figures worked to when laying out the Aldershot system may be cited :—

Feeders	7½ per cent.
Main distributors	12½ ,, ,,
Branch distributors	20 ,, ,,
Services	50 ,, ,,

2. The next step is to work out the sizes of the conductors for a 2-wire system, *at the declared lamp voltage*, making assumptions regarding the percentage loss permissible in the various component parts of the systems.

Let R_2 = resistance of each conductor of a 2-wire system at voltage V.
R_3 = resistance of outer conductor of a 3-wire system at voltage 2V.
I_2 = maximum current in the 2-wire conductor.
I_3 = maximum current in the 3-wire outer conductor.
γ = ratio of resistance of mid-wire to outer of the 3-wire system.
m = percentage out-of-balance in the 3-wire system.
V.D. = maximum permissible voltage drop (same for each system).

Then on the 2-wire system,

$$\text{V.D.} = 2I_2R_2.$$

Also on the 3-wire system,

voltage drop on more heavily loaded outer $= I_3R_3$,

and voltage drop on mid-wire $= I_3 \times \frac{m}{100} \times R_3\gamma$,

$$\text{so that V.D.} = I_3R_3\left(1 + \frac{m\gamma}{100}\right).$$

$$\therefore 2I_2R_2 = I_3R_3\left(\frac{100 + m\gamma}{100}\right).$$

But $I_2 = 2I_3$,

$$\therefore 4I_3R_2 = I_3R_3\left(\frac{100 + m\gamma}{100}\right),$$

$$\therefore R_3 = R_2\left(\frac{400}{100 + m\gamma}\right) \dots\dots\dots\dots\dots\dots (1).$$

It can also be proved that, for a minimum total weight of copper, m being constant,

$$\gamma = \sqrt{\frac{50}{m}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2).$$

Equations (1) and (2) will enable the sizes of all conductors on the 3-wire system to be determined, and curves representing the equations are given on Pl. **52.**

4. It will be noticed that with perfect balance ($m = 0$), R_3 could be four times as great as R_2, as explained in the elementary consideration of the economics resulting from this system, whereas with a 50 per cent. out-of-balance $R_3 = \frac{8}{3}R_2$, and the total amount of copper necessitated by the 3-wire system is $\frac{9}{16}$ of that needed by the 2-wire system.

Example.—Suppose a 0·1 sq. inch conductor to be necessary on a 2-wire system of voltage V.

Let A_2 = conductor cross-section on 2-wire system (voltage V).

Let A_3 = cross-section of outer conductor of 3-wire system (voltage 2V).

Let A_m = cross-section of midwire conductor of 3-wire system (voltage 2V),

and assume 15 per cent. out-of-balance.

$$\gamma = \sqrt{\frac{50}{m}} = \sqrt{\frac{50}{15}} = 1{\cdot}82$$

$$R_3 = R_2\left(\frac{400}{100 + m\gamma}\right) = \left(\frac{400}{100 + 15 \times 1{\cdot}82}\right)R_2 = 3{\cdot}14R_2.$$

$$\therefore A_3 = \frac{A_2}{3{\cdot}14} = \frac{0{\cdot}1}{3{\cdot}14} = 0{\cdot}0318$$ sq. in. (nearest standard 0·04 sq. in.)

and $$A_m = \frac{0{\cdot}0318}{1{\cdot}82} = 0{\cdot}0175$$ sq. in. (nearest standard 0·0225 sq. in.)

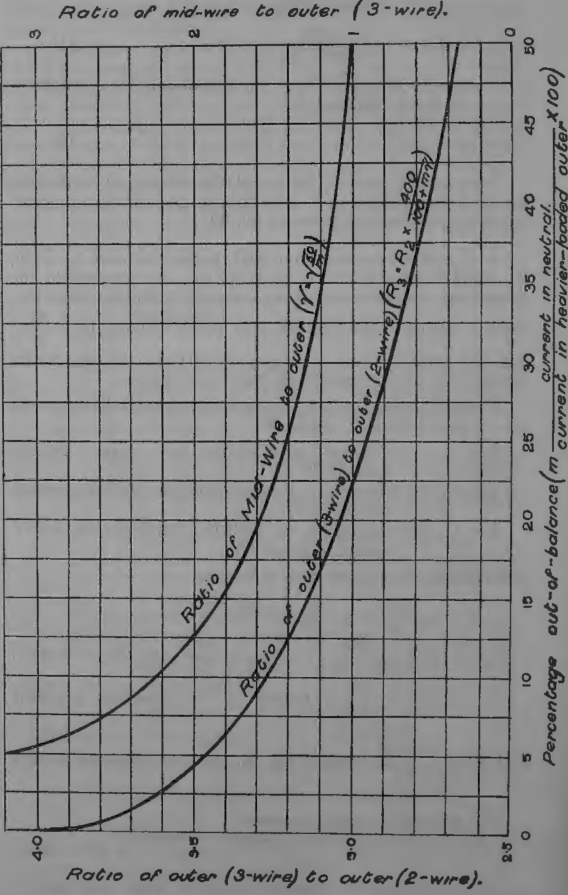
The percentage saving in copper

$$= \frac{(0{\cdot}1 + 0{\cdot}1) - (0{\cdot}0318 + 0{\cdot}0318 + 0{\cdot}0175)}{0{\cdot}2} \times 100 = 59\%.$$

If, as is now the modern practice when the load is

PLATE 52.

RESISTANCE RATIOS. (3-wire distribution).



practically all lighting, the ***mid-wire is made equal in section to the outers***

$$\gamma = 1$$

$$R_3 = \frac{400}{115}R_2 = 3{\cdot}48R_2$$

$$A_3 = \frac{0{\cdot}1}{3{\cdot}48} = 0{\cdot}0287 \text{ sq. in. (nearest standard } 0{\cdot}03 \text{ sq. in.)}$$

and the percentage saving in copper

$$= \frac{(0{\cdot}1 + 0{\cdot}1) - (3 \times 0{\cdot}0287)}{0{\cdot}2} \times 100 = 57 \text{ per cent.}$$

The theoretical saving is, therefore, not quite as much in this case, but in point of fact, in the example chosen, the weight of copper is considerably less when the three cores are of equal section than when the mid-wire is of smaller section than the outers. This is due to the necessity for choosing conductors of standard section.

It will be observed that the practical saving is less than that arrived at in Sec. **31**, when " out-of-balance " was not taken into account.

34. *A.C. distribution.*

1. Methods of distribution by A.C.—The simplest is single-phase 2-wire, but single-phase 3-wire is also met with and has the same advantage over single-phase 2-wire that 3-wire D.C. has over 2-wire. However, A.C. distribution is most commonly carried out 3-phase, which was introduced not to secure economy in copper but on account of the fact that 3-phase machinery is less expensive and more efficient in operation than single-phase. From a purely lighting point of view the 3-phase system has little advantage over the single-phase.

The maximum economy in copper for lighting circuits cannot be secured with 3-phase 3-wire distribution, but, if the L.V. side of the transformer be star-connected and a fourth wire run, the advantage of distribution at $V\sqrt{3}$ volts (if V is the lamp voltage) is obtained. As V is limited to 250, distribution can be made at $250\sqrt{3}$ between lines, *but the neutral must be earthed.*

Motors will be connected to the 3-phase wires only.

The principal advantages of 3-phase 4-wire over 3-phase 3-wire distribution may be stated as follows :—

i. Large saving in capital cost of conductors.
ii. Less variation of voltage due to want of balance.
iii. Less inconvenience to consumers in case of any one phase being interrupted.

2. Use of static balancer.—It may sometimes be found that the most convenient supply consists of a 3-phase 3-wire power line at 400 to 430V. A lighting load can be connected to such a line without the necessity for running a fourth wire back to the generating station by the installation of a static balancer, which consists of an interconnected star winding on an iron core similar to the low voltage winding of a transformer (Fig. 37). The static balancer also obviates the necessity for having a Delta-Star transformer at the sub-station.

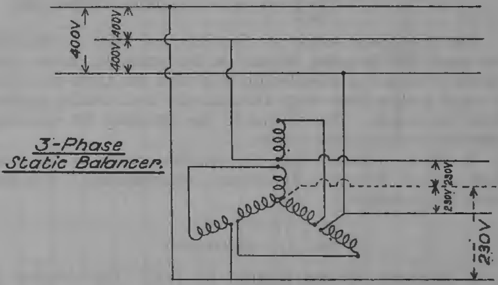


Fig. 37.

3. Weights of copper required in the various practical L.V. distribution systems.—If the amount of energy to be transmitted and the percentage loss to be allowed in the line are laid down, the systems may be compared on the basis of equal maximum or virtual voltage either between conductors or between conductors and earth.

In making comparisons between A.C. and D.C., it should be noted that, while in the case of D.C. the maximum voltage will not exceed the effective voltage, in the case of A.C. the maximum voltage will be $\sqrt{2}$ times the effective voltage. The D.C. system would, therefore, on the basis of equal maximum voltage, be expected to require only half the amount of copper that is wanted in the A.C. system.

Although the maximum voltage is of great importance with H.V. conductors, it is of little importance in ordinary L.V. and M.V. feeders and distributors, firstly, because cables are not made for voltages less than 660V (effective), and, secondly, because from mechanical considerations the electrical factor of safety of L.V. cables is very high.

It is, therefore, proposed to compare the systems on the basis of :—

i. Equal voltage at lamps.
ii. Equal amounts of energy transmitted.
iii. Equal per cent. voltage drop in line.

i.e., the following standard systems will be compared :—

i. D.C. 2-wire 230V.
ii. D.C. 3-wire 230/460V.
iii. A.C. single-phase 2-wire 230V.
iv. A.C. single-phase 3-wire 230/460V.
v. A.C. 3-phase 3-wire 230V.
vi. A.C. 3-phase 4-wire 230/400V.

In Sec. 31 D.C. 3-wire is shown to require only 25 per cent. of the weight of copper required for D.C. 2-wire (if the neutral be neglected). A.C. single-phase 2-wire and 3-wire systems require respectively exactly the same amounts of copper as D.C. 2-wire and 3-wire systems if power factor is neglected.

Let V_1, I_1, and R_1 = line voltage, line current, and line resistance respectively for single-phase 2-wire, and V_3, I_3, and R_3 = the values for 3-phase systems.

3-phase 3-wire.—For equal amounts of power

$$\sqrt{3}V_3I_3 = V_1I_1.$$

But $V_3 = V_1$, so that $I_3 = \frac{I_1}{\sqrt{3}}$.

For equal voltage drop $\sqrt{3}\,.\,I_3R_3 = 2I_1R_1$,

$$\therefore R_3 = \frac{2I_1R_1}{\sqrt{3}I_3} = \frac{2I_1R_1\sqrt{3}}{\sqrt{3}\,.\,I_1} = 2R_1,$$

i.e., the section of each conductor is required to be only one-half the section of the conductors in the single-phase system. Three conductors are required ; therefore, the ratio of weights is 3-phase 3-wire : single-phase 2-wire = 0·75 : 1.

3-phase 4-wire.—Total power = $\sqrt{3}V_3I_3 = V_1I_1$ as before, but in this case $V_3 = \sqrt{3}V_1$,

$$\therefore I_3 = \frac{I_1}{3}.$$

For equal voltage drop $I_3R_3 = 2I_1R_1$.

$$\therefore \frac{I_1}{3}R_3 = 2I_1R_1.$$

$$\therefore R_3 = 6R_1.$$

Therefore, ratio of weights is 3-phase 4-wire : single-phase 2-wire = 0·25 : 1.

A little thought will show that a similar result would have been obtained if equal line power losses had been considered instead of equal line voltage drops. But this is only correct when the power factor is unity.

If it be assumed that a neutral of section equal to that of the other conductors is installed in all cases, the following comparative figures are obtained :—

D.C.		A.C. single-phase.		A.C. 3-phase.	
(i) 2-wire	(ii) 3-wire	(iii) 2-wire	(iv) 3-wire	(v) 3-wire	(vi) 4-wire
1	0·375	1	0·375	0·75	0·333

The above comparison neglects the all-important question of *power factor*, the effects of which will now be considered.

4. **Effect of power factor.**—It was shown in Chap. III that the voltage drop in an A.C. line is given by $V_1 - V_2 = RI \cos \phi + XI \sin \phi$ (neglecting capacitance).

i. In *cable systems*, X is relatively small, and as a first approximation we may say that $V_1 - V_2 = RI \cos \phi$. From this it follows that, although the current with inductive load is greater than that with non-inductive load in the ratio $\frac{I}{\cos \phi}$ to I, the voltage drop is practically the same whether the load is inductive or not.

But when the heating loss is considered in the two cases a very different result is obtained, as this loss will be increased from I^2R to $\frac{I^2R}{\cos^2 \phi}$, *i.e.*, the heating loss will be inversely proportional to the square of the P.F. of the load.

If the P.F. is 0·8 (a very common practical figure), the heating losses will be 56 per cent. greater than when the P.F. is unity. This is the chief disadvantage in the distribution of A.C. at low voltage, and the result is that the area which can be covered economically by an A.C. L.V. distribution system is less than by D.C., although with a lighting load the difference is inappreciable. With a mixed power and lighting load the full-load P.F. will vary from 0·8 to 1, and where induction motors preponderate the value will be from 0·6 to 0·8.

To sum up, it may be stated that the weight of copper required in A.C. *cable* systems when the load is non-inductive is about the same as required by D.C. systems for the same percentage voltage drop.

When the P.F. is low, although the drop may not be much increased, more copper may have to be put in to keep the heating within safe limits.

ii. With *overhead lines*, the heating effect may generally be neglected (except in so far as it reduces the efficiency of the system), but the line reactance is appreciable, and a low P.F.

[To face p. 172.

LINE REACTANCE

PLATE 55.
(See Section 346)

Fig 1. Variation of reactance with distance between conductors

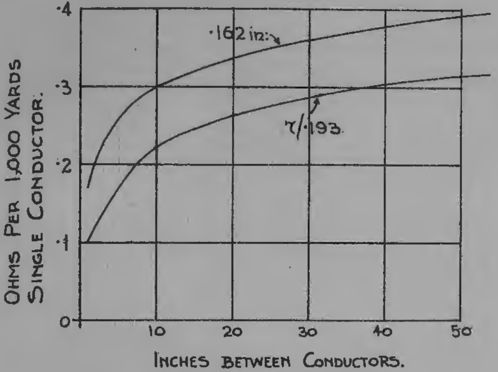


Fig:2. RESISTANCE AND REACTANCE OF COPPER CABLES AND OVERHEAD LINES (3 FEET SPACING).

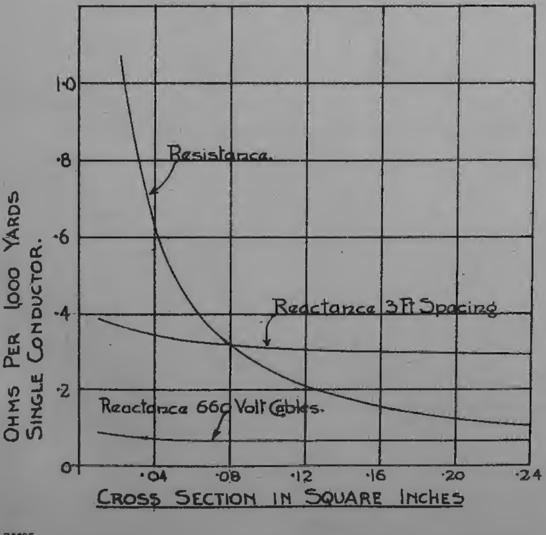


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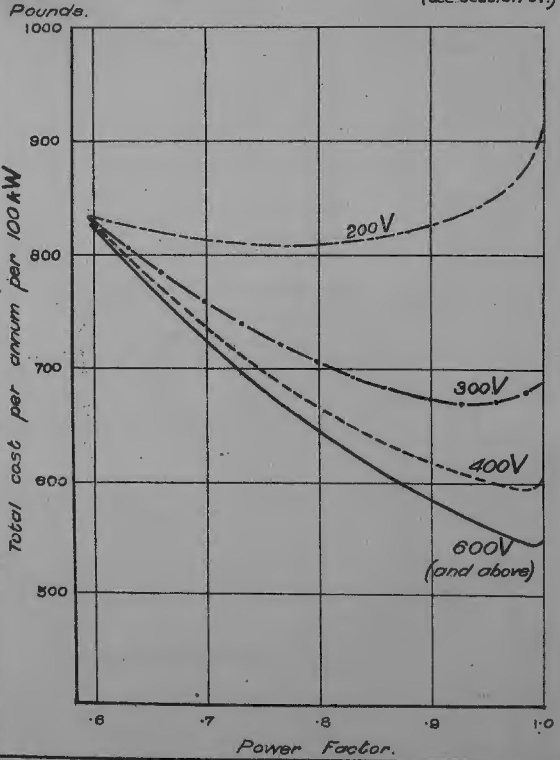
Plate 54.

POWER FACTOR CORRECTION CURVES.

(See Section 34.)



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may necessitate putting in larger conductors to keep down the voltage drop.

It must be emphasized that A.C. is not suitable for the economical distribution of large amounts of power by L.V. overhead conductors, owing to the effect of this line reactance, particularly when the load P.F. is low.

From the formula for inductance (*see* Sec. **19**, para. 2), it will be apparent that the effect of separating the wires does not vary directly with their distance apart.

Pl. **53**, Fig. 1, shows the variation of reactance with distance of separation.

It will be noted that the reactance increases rapidly as the separation is increased up to six inches, and less and less rapidly as the separation further increases.

This is a fortunate condition for overhead lines operating at very high voltages which require large clearances to guard against short-circuits and in which the currents are relatively small.

Unfortunately bare L.V. overhead lines, in which the currents are relatively very much larger, also require clearances of 12 inches or more for satisfactory working (*see* Sec. **51**, para. 2), and the drop may become prohibitive with quite moderate currents and distances.

In underground cables the conductors may be brought very close together, and the economical distribution of heavy low-voltage currents will not be affected appreciably by the effect of line reactance.

For a given spacing, as the conductor section increases, both reactance and resistance become individually smaller, but the ratio $\frac{\text{reactance}}{\text{resistance}}$ increases rapidly (*see* Pl. **53**, Fig. 2). For this reason, increasing the area of A.C. conductors (particularly overhead) for the purpose of reducing the voltage drop becomes less effective after the size is increased above the point where the resistance is about equal to the reactance.

Therefore, with heavy L.V. currents where the line drop would be excessive with a conductor of large section, two or more circuits of smaller wires in parallel would give better results. A state of affairs, however, requiring such treatment would generally indicate that the economic limits of L.V. distribution were being exceeded and that a H.V. branch line would best meet the case.

5. A.C. Network Calculations.—The methods described in Secs. **28** and **29** can be applied directly to A.C. networks, if the line reactance and load P.F. are neglected, but when these factors are considered, anything like a complete analysis becomes extremely difficult.

It is generally sufficient in a complicated network to calculate for non-inductive conditions, and then to make a reasonable allowance for the average P.F. which is expected.

A few simple examples will now be given.

6. Example of calculation for simple A.C. feeder.—3-phase, 4-wire, 400/230 volts, 300 yards long. Maximum voltage drop 3 per cent with balanced load.

(i) *Maximum lighting load of* 100*kW*.

(*a*) *Cable—Main Conductors.*—Maximum current per line (balanced load)

$$= \frac{100{,}000}{400\sqrt{3}} = \frac{250}{\sqrt{3}} \text{ amps.}$$

$$\textit{Voltage drop} = \sqrt{3}(\mathrm{RI}\cos\phi + \mathrm{XI}\sin\phi) = 12 \text{ volts.}$$

$$\cos\phi = 1 \text{ and } \sin\phi = 0$$

$$\therefore \sqrt{3} \times \frac{250}{\sqrt{3}} \times \mathrm{R} = 12$$

$$\text{and } \mathrm{R} = \frac{12}{250} = 0{\cdot}048 \text{ ohm for 300 yards.}$$

$$\therefore \text{ maximum R per 1,000 yards} = 0{\cdot}048 \times \frac{1{,}000}{300} = 0{\cdot}16 \text{ ohm.}$$

Nearest standard conductor = 0·15 sq. in. (R = 0·1625 ohm per 1,000 yards).

(*b*) *Cable—neutral conductor.*—The usual practice is to put in a neutral conductor equal in section to the other conductors, when the load is practically all lighting. Even so, the drop in the neutral due to "*incidental out-of-balance*" must always be considered. The remarks in Sec. **32**, regarding the necessity for ensuring that there shall be as little as possible "*installed out-of-balance*" apply with equal force to 3-phase lighting loads. In the worst possible case, with full load on one phase and no load on the other two, the drop in the neutral will be equal to that in the line conductor and, therefore, the total drop will be double the value allowed for above. Such a state of affairs is, of course, abnormal, and with ordinary care in the layout of the system, the maximum out-of-balance drop in the neutral should not exceed 25 per cent. of the line conductor drop. That is, in our example using four 0·15 sq. in. conductors, calculated to give a maximum voltage drop of 3 per cent. with balanced load, a maximum drop of 3·75 per cent. may be expected at times, due to *incidental out-of-balance.*

(*c*) *Overhead lines.*—In the case of a purely lighting load, the increased drop, due to line reactance is inappreciable, therefore the same size of conductors will meet the case.

(ii) *Maximum Load:* 50*kW* *Lighting*, 50*kW* *Power at* 0·7 P.F.

(*a*) *Cable—Main Conductors.*—Lighting current (balanced load)

$$= \frac{50{,}000}{400\sqrt{3}} = \frac{125}{\sqrt{3}} \text{ amps.}$$

$$\text{Power current} = \frac{50{,}000}{400\sqrt{3} \times 0{\cdot}7} = \frac{179}{\sqrt{3}} \text{ amps.}$$

$$\text{Total watt component} = \frac{125}{\sqrt{3}} + \frac{125}{\sqrt{3}} = \frac{250}{\sqrt{3}} \text{ amps.}$$

$$\text{Wattless component} = \frac{179}{\sqrt{3}} \sin\phi = \frac{179}{\sqrt{3}} \times 0{\cdot}714 = \frac{128}{\sqrt{3}} \text{ amps.}$$

$$\text{Total current} = \sqrt{\left(\frac{250}{\sqrt{3}}\right)^2 + \left(\frac{128}{\sqrt{3}}\right)^2} = 162 \text{ amps.}$$

$$\cos\phi = \frac{\frac{250}{\sqrt{3}}}{162} = 0{\cdot}89.$$

$$\text{V.D.} = \sqrt{3}\,(\text{RI}\cos\phi + \text{XI}\sin\phi) = 12 \text{ volts.}$$

$$\therefore 0{\cdot}89\text{R} + 0{\cdot}46\text{X} = \frac{12}{162\sqrt{3}}$$

Assuming the reactance of 660-volt cable to be 0·06 ohm per 1,000 yards,

$$\text{X} = 0{\cdot}06 \times 0{\cdot}3 = 0{\cdot}018 \text{ ohm.}$$

Substituting this in the expression for the voltage drop, we get R = 0·039 ohm.

$$\therefore \text{ maximum resistance per 1,000 yards} = 0{\cdot}039 \times \frac{1{,}000}{300}$$

= 0·13 ohm.

The nearest standard size is 0·2 sq. in. (resistance 0·1223 ohm per 1,000 yards).

(*b*) *Cable—neutral conductor.*—See (i) (*b*) above. As the load is only half lighting, a neutral conductor of section 0·1 or 0·12 sq. in. would normally meet the case.

(*c*) *Overhead lines.*—The line reactance will now be about 0·27 ohm per 1,000 yards, *i.e.* 0·081 ohm for 300 yards.

$$\text{V.D.} = \sqrt{3}\,(\text{RI}\cos\phi + \text{XI}\sin\phi) = 12 \text{ volts.}$$

$$0{\cdot}89\text{R} + 0{\cdot}081 \times 0{\cdot}46 = \frac{12}{162\sqrt{3}}$$

and R = 0·0061 ohm.

i.e. maximum resistance of conductor required = 0·0203 ohm per 1,000 yards.

Reference to Appendix VI will show that the conditions can only be satisfied by quite abnormal conductors.

The problem might be solved by increasing the drop to 10 per cent. (in which case 0·075 sq. in. conductors would do) and installing an automatic voltage regulator, but the most practical solution would be a H.V. branch feeder.

7. A.C. Distributor.—The simple case of three loads, each of 100A and of P.F. 0·7, 1·0, and 0·8, situated 100, 200 and 300 yards respectively along a distributor fed at one end (Fig. 38), will be considered briefly.

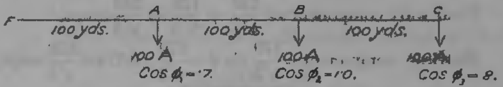

Fig. 38.

Each current may be split up into its watt and wattless components at right angles. These will be :—

Load A. $100 \cos\phi_1 = 70\text{A}.$ $100 \sin\phi_1 = 70\text{A}.$
,, B. $100 \cos\phi_2 = 100\text{A}.$ $100 \sin\phi_2 = 0.$
,, C. $100 \cos\phi_3 = 80\text{A}.$ $100 \sin\phi_3 = 60\text{A}.$

These may be represented as in Fig. 39.

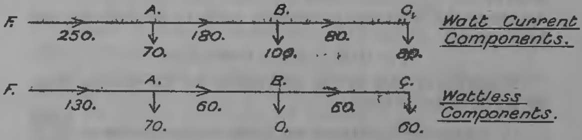

Fig. 39.

$\therefore$ current in section FA $= \sqrt{250^2 + 130^2} = 282\text{A}.$
,, ,, AB $= \sqrt{180^2 + 60^2} = 190\text{A}.$
,, ,, BC $= \sqrt{80^2 + 60^2} = 100\text{A}.$

Cosine of angle of lag in section FA $= \frac{250}{282} = 0{\cdot}887.$
,, ,, ,, AB $= \frac{180}{190} = 0{\cdot}947.$
,, ,, ,, BC $= \frac{80}{100} = 0{\cdot}8.$

(i) *Single-phase, 2-wire Cable.*

V.D. from F to C

$$= \frac{2R}{1{,}000}(250 \times 100 + 180 \times 100 + 80 \times 100)$$
$$+ \frac{2X}{1{,}000}(130 \times 100 + 60 \times 100 + 60 \times 100)$$
$$= 102R + 50X.$$

R and X being respectively the resistance and reactance per 1,000 yards of single conductor.

The smallest suitable two-core armoured cable *from a heating point of view* is 0·15 sq. in. (*see* Appendix VII), for which R and X = 0·1625 and 0·064 ohm respectively (*see* Appendix VI and Pl. **53**)

$\therefore$ V.D. = 102 × 0·1625 + 50 × 0·064 = 19·77 volts.

(ii) *Three-phase, 3-wire.*

(*a*) *Cable.*

$$\text{V.D. from F to C} = (102\text{R} + 50\text{X})\frac{\sqrt{3}}{2} \text{ (\textit{see} Sec. \textbf{19}, para. 5)}$$
$$= 88\text{R} + 43\text{X}$$

The smallest 3-core armoured cable suitable from a heating point of view is 0·2 sq. in. for which R = 0·1223 and X = 0·063.

$$\therefore \text{V.D.} = 88 \times 0{\cdot}1223 + 43 \times 0{\cdot}063$$
$$= 10{\cdot}67 + 2{\cdot}71 = 13{\cdot}38 \text{ volts.}$$

(*b*) *Overhead line.*

Assuming R to be the same, and taking X = 0·27 ohm, V.D. = 10·67 + 43 × 0·27 = 10·67 + 11·61 = 22·28 volts.

(iii) *Three-phase, 4-wire.*—The same reasoning applies as was given in the A.C. Feeder calculations.

(iv) *Per cent. voltage drop.*—Assuming standard voltages, the drop in the single-phase case is $\frac{19{\cdot}77}{230} \times 100 = 8{\cdot}6$ per cent.

and in the three-phase case it is $\frac{13{\cdot}38}{400} \times 100 = 3{\cdot}34$ per cent.

for cable, and $\frac{22{\cdot}28}{400} \times 100 = 5{\cdot}47$ for overhead line.

All these figures are much too high for distributors in which the V.D. should not, in any circumstances, exceed 2 per cent., but the calculations should serve to *emphasize the importance of reducing the amount of L.V. distribution to a minimum.*

The magnitude of the loads at A, B and C most certainly justify a transformer sub-station at the point B.

8. **A.C. *versus* D.C. distribution.**—The advantage of D.C. over A.C. distribution from a *weight of copper* point of view is not sufficient to justify converting H.V. A.C. to D.C., except in a few special cases.

Reference to Chap. XIII will show that reliable A.C. motors may now be obtained for most requirements, and conversion for ordinary power purposes, *e.g.*, workshops, pumping, laundry, mill, and bakery machinery, is not necessary nor good practice.

It should be noted that in the single-phase 3-wire and the

3-phase 4-wire systems there is no trouble from electrolysis as there is with D.C. 3-wire, and, further, no running machinery is required for balancing in the A.C. systems.

9. **Power factor improvement.**—The effect of a low P.F. in increasing the heating losses in the mains has been pointed out in para. 4, but in addition it reduces the capacity of generators and transformers and adversely affects their regulation. These effects are so troublesome to electricity supply companies that clauses are now frequently inserted in contracts for supply penalizing consumers who do not keep up their P.F. In some cases a minimum P.F. of 0·8 is specified; in others a fixed charge per **kVA** of maximum demand is made plus a small charge per unit consumed.

Induction motors are the most prolific causes of low P.F., and, although great progress is being made in the design of A.C. commutator motors with high P.Fs., the wholesale replacement of induction motors by such machines is improbable. However, a good deal can be done by stipulating for high P.Fs. when purchasing, by avoiding the use of small machines which are liable to run light for long periods, and in taking care not to install motors that are too big for their work. It may sometimes be advantageous so to group machines that one large motor, running normally from $\frac{1}{2}$ to $\frac{3}{4}$ full load, takes the place of several smaller machines. High-speed motors have better P.Fs. than those of low speed. Very small motors should have ball-bearings and minimum possible air gaps.

Although much good may be done by attention to the points indicated above, it will seldom be found possible to keep up the average P.F. of an ordinary machine-shop much above 0·6, and the advisability of installing special corrective machinery or apparatus should be carefully considered. The following devices are available :—

i. Phase advancers.
ii. Rotary condensers.
iii. Static condensers.

i. *Phase advancers.*—The term *phase advancer* is sometimes employed for any type of apparatus for P.F. correction, but it is better to reserve it for the small commutator machines which are frequently installed with large slip-ring induction motors. These machines are so designed and connected that a leading E.M.F. is applied to the rotor windings. This results in the rotor windings becoming the exciting windings, and the stator windings are thus relieved of the wattless magnetizing current. This method of correction differs from those described hereafter in that the P.F. of the machine itself is improved, thus enabling the H.P. rating to be somewhat increased. Unfortunately, the addition of the phase advancer increases the overall cost of the machine unduly for sizes below about 100 B.H.P.

ii. *Rotary condensers.*—Synchronous motors when over-excited take a leading current from the mains, and this principle has been largely made use of for P.F. correction. Full-load current can easily be obtained even when running light, but it is better to load the machines, since a considerable leading wattless current can be carried for a relatively small increase in their **kVA** capacity. Objections to rotary condensers are :—

(*a*) A D.C. supply is required for their fields.
(*b*) Skilled attention is required during operation.
(*c*) Cost is relatively high.
(*d*) Efficiency is low compared with static condensers.

These objections rule the machines out of consideration except in cases where large units, say, of 200 B.H.P. and upwards, can be usefully employed.

iii. *Static condensers.*—Static condensers can now be obtained at a cost of about £3 per **kVA** for voltages of 600V and upwards. They are usually manufactured in 600V units, five of which may be connected in series for 3,000V. As the 600V units are the only ones available, for all lower voltages the cost per **kVA** will be inversely proportional to the square of the voltage, *e.g.*, for 200V circuits the cost will be

$$\frac{600^2}{200^2} \times 3 = £27 \text{ per } \mathbf{kVA}.$$

In certain cases, however, where the voltage of supply is less than 600V, it is possible to reduce the cost of the condenser either by—

(*a*) Installing an inductance in series with the condenser.
(*b*) Stepping-up the supply voltage by means of an auto-transformer to 600V at the condenser terminals.

As an example the case of a 100kW load at 0·6 P.F. will be considered, the Supply Company's charge being £5 per annum per **kVA** of maximum demand. The cost of condenser will be taken to be £3·5 per **kVA** (including the cost of switchgear and erection) and 10 per cent. per annum will be assumed as the annual charge for interest and depreciation. Table **D** and the curves on Pl. **54** show how the total annual standing charge varies with the P.F. at 200V, 400V, and 600V respectively. The curve for 600V applies also to H.V. voltages if the step-down transformer is not considered.

It will be noted that :—

i. A much larger capacitance is required to raise the P.F. by a given percentage when it is near unity than when it has a much lower value.

TABLE D.—*Economy resulting from the installation of condensers to improve the power factor.*

Final P.F.	Total kVA.	Annual charge at £5 per kVA.	Wattless kVA.	Capacity kVA.	Annual charge per **kVA** for capacity.			Total annual charge.		
					600V.	400V.	200V.	600V.	400V.	200V.
					£0·35.	£0·787.	£3·15.			
		£			£	£	£	£	£	£
0·6	166·7	833·5	133·3	0	—	—	—	833·5	833·5	833·5
0·7	143·0	715·0	102·0	31·3	10·97	24·62	98·7	726	739·5	813·5
0·8	125·0	625·0	75·0	58·3	20·4	46·0	184·0	645·6	671	809
0·9	111·1	555·5	48·4	84·9	29·7	66·87	267·5	585	622·5	823
0·91	110·0	550·0	45·6	87·7	30·7	69·12	276·5	580·5	619	826·5
0·92	108·7	543·5	42·6	90·7	31·8	71·5	286·0	575·5	615	829·5
0·93	107·6	538·0	39·5	93·8	32·8	73·87	295·5	571	612	833·5
0·94	106·5	532·5	36·3	97·0	34·0	76·5	306·0	566·5	609	838·5
0·95	105·2	526·0	32·9	100·4	35·2	79·12	316·5	561	605	842·5
0·96	104·2	521·0	29·18	104·12	36·5	82·12	328·5	557·5	603	849·5
0·97	103·1	515·5	25·1	108·2	37·9	85·5	342·0	553·5	601	857·5
0·98	102·0	510·0	20·3	113·0	39·5	89·0	356·0	549·5	599	866
0·985	101·5	507·5	17·6	115·7	40·5	91·0	364·0	548	598·5	871·5
0·99	101·0	505·0	14·23	119·07	41·7	94·0	376·0	546·5	599	881
0·995	100·5	502·5	10·5	122·8	42·9	96·5	386·0	545·5	599	888·5
1·00	100·0	500·0	0	133·3	46·65	105·0	420·0	546·5	605	920

ii. It is not economical to raise the P.F. to unity. (It is seldom worth while raising it above 0·95.)

iii. Very little economy can be effected at 200V, but even at this voltage it is practicable to use condensers to bring up the P.F. from 0·6 to 0·8.

These considerations are based on the assumption that the capacitance is located at the centre of the distribution on the delivery side of the step-down transformer, in which case the transformer, as well as the H.V. mains and generating station, is relieved of wattless **kVA.** At first sight it might be thought ideal to have a separate condenser for each motor and so relieve the distributing mains as well, but with the relatively small machines used for military purposes it will be found more economical to install sufficient capacitance at the sub-station to improve the P.F. of the installation as a whole.

From the curves given on Pl. **54** it might appear that in 400 to 480V installations it would be more economical to install the condensers on the H.V. side, but it must not be overlooked that the step-down transformer is not relieved by this arrangement, and it will, therefore, have to be much larger than it would be if the condensers were on the delivery side.

In 200 to 240V installations it may be found more economical to place the condensers on the H.V. side of the transformer.

Static condensers are undoubtedly the most satisfactory type of apparatus to use for P.F. improvement. They require no attention, and the energy loss in them is negligible.

On voltages below 600V, condensers should be connected in mesh in 3-phase circuits to get the maximum effect from a given total capacitance. On ordinary H.V. voltages it does not much matter whether they are connected in star or mesh.

It is desirable that the condensers should be subdivided, so that the capacitance in use can be approximately adjusted to suit the number of motors working.

35. *Changing over D.C. Systems to A.C.*

1. The solution to the problem of converting a D.C. system to A.C. with the least possible disturbance of supply is almost entirely one of organization and forethought. The chief technical question is the utilization of as much as possible of the existing distribution network.

2. **Cables.**—Where overhead lines are in use the obvious method is to run a fourth conductor and balance up the load on the three phases of the 4-wire A.C. distribution. With cables, of course, the above procedure is impracticable, and if they are single-core and armoured there is no possible method of using them, as the induced currents cause prohibi-

tive losses and heating in the armouring, and excessive voltage drop. If, however, three-core distributors are in use the 3-phase H.V. supply can be transformed into two single-phase L.V. 3-wire supplies by means of Scott-connected transformers (for which *see* Bibliography). The middle point of each L.V. winding is connected to the old D.C. neutrals, and the load balanced between the two phases.

3. **Apparatus.**—A change from D.C. to A.C. of approximately the same voltage does not affect heating and cooking apparatus, but new motors and **kWh** meters will be necessary in all cases, except perhaps for certain small apparatus such as vacuum-cleaners and fans, some designs of which may possibly work more or less satisfactorily on A.C.

Difficulty may be found when changing motors owing to the poor starting torque and the limited number of speeds available with A.C. machines. The question is dealt with in Sec. **90**.

4. **Standard voltage.**—Where the D.C. supply is of a non-standard voltage opportunity should be taken to alter to the standard A.C. voltage of 400/230 volts.

5. During the actual change over the area must be divided into small sections, and no attempt made to expedite matters by doing more than one section a day, with two or three days' interval between sections. Close co-operation with the R.A.S.C. in connection with meter changing is essential.

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CHAPTER V.

CABLES AND WIRES.

36. *Conductors.*

1. **Copper** was almost exclusively employed in the early days of the electrical industry for electrical conductors, whether in underground cables, for overhead lines, or for bus-bars, &c., and it is still almost universally used for underground cables. Its chief advantage is its low specific resistance, but it must be remembered that this largely depends upon its purity and the physical treatment it has undergone. For instance, the conductivity of copper produced by an ordinary smelting process may be only 50 per cent. of that of electrolytically refined copper.

W.D. specifications for cables invariably state that the standards of purity and conductivity of the copper shall be those of the British Engineering Standards Association for annealed high-conductivity commercial copper. This ensures that the resistance shall not exceed $1{\cdot}59\mu\mathbf{O}$ per centimetre cube, or $0{\cdot}625\mu\mathbf{O}$ per inch cube, at 0° C., with a temperature coefficient of approximately 0·004 per °C.

Hard-drawn copper wire is more than twice as strong as annealed copper wire, but its resistance is a little greater and it is not nearly so soft and pliable, so the wires or strands of a cable conductor are almost invariably of the annealed variety.

To give flexibility the cores are *stranded*, *i.e.*, made up of a number of small wires, except in the case of the very smallest insulated wires. In the case of single-core cables, this stranding is always so arranged as to give and preserve a cylindrical form. Thus the number of strands will be found to be 3, 7, 19, 37, 61, 91, or 127, all, excepting in the case of the 3-strand, being laid up round one central wire. Each strand, except the centre one, is, on account of the laying up, approximately 2 per cent. longer than the cable ; consequently the resistance of a stranded cable is approximately 2 per cent. higher than solid copper of equal weight per mile, for, owing to the comparatively poor contact between strands, the shortest *electrical* path is along the strands.

Multicore cables are discussed in Sec. **40.**

2. **Aluminium,** though often used for bare overhead lines (*see* next chapter), has not been employed to any considerable extent for insulated cables owing to the extra quantity of insulation, &c., required. For a given length and resistance the weight of aluminium is about half that of copper, but the

weight of the complete aluminium cable would in most cases be greater than that of the equivalent copper cable. The jointing of aluminium is always a difficult matter.

The use of cables and wires with aluminium conductors in the military service is not recommended.

3. **Steel** is only employed as a conductor where tensile strength is of paramount importance and where conductivity is a minor matter, such as in the Service D cables for field use. Its resistivity is from 6 to 10 times that of copper.

37. *Insulation.*

1. Cables and wires can be conveniently classified according to the type of insulation. The ideal insulation for cables, besides being of high specific resistance, should be impervious to moisture, flexible though tough, capable of standing high temperatures without deterioration, chemically inert, proof against high disruptive voltages, homogeneous and preferably non-inflammable, but it is, of course, rather too much to expect any one substance to possess all these qualities. The actual purpose for which the cable is required, its proposed situation, and the proposed method of laying combine to determine which of these qualities are most desirable, and selection must be made accordingly, though the cost is also a matter of considerable importance.

The insulating materials commonly used may be divided into the following groups :—

i. Rubber.
ii. Gutta percha.
iii. Vulcanized bitumen, either solely or in conjunction with fibrous material.
iv. Fibrous material, such as paper or jute yarn.
v. Silk, cotton, enamel.

2. **Rubber.**—For very many years rubber was the only material used for the insulation of cables, and but for the cost it is doubtful whether it would have been superseded. It is still largely used for smaller cables and where high insulation and ease of fixing and manipulation are primary considerations, but it is variable in its behaviour, and difficulty has been experienced in devising tests to ensure the exclusion of inferior material. If the rubber is of good quality and the cables are kept dry and cool, a long life may be expected, but condensed moisture is especially deleterious in its action on rubber, and it will not stand so high a temperature as paper without deterioration. If rubber-insulated cables are drawn into wet ducts or, which is worse, into ducts which are sometimes wet and sometimes dry, breakdown will probably occur within 7 or 8 years.

Pure rubber becomes brittle on exposure to air, and cannot stand a higher temperature than 136° F., so vulcanized rubber, which is composed of pure rubber mixed with about one-twentieth of its weight of sulphur and various other ingredients and heated to about 300° F., was introduced. This compound is much stronger, more durable, cheaper, able to withstand higher temperatures, and retains its elasticity better than pure rubber.

In making up rubber cables the conductor must first of all be *thoroughly well tinned*, to prevent the serious and rapid deterioration of the insulation which results from contact between the rubber and the copper. The importance of perfect tinning cannot be over-estimated, and this is a point that must be carefully borne in mind when jointing. A very small blemish in the tinning process might not be detected on test, and it may take years to develop into a fault, but this fault, when it does develop, may be the cause of shutting down a whole area. In the testing of cables the quality of the tinning is judged by the appearance of the wire or rubber after vulcanization; heavy blackening of the wire or discoloration of the rubber should cause rejection.

The tinned conductor may first be given a lapping of pure rubber, the object of this being to ensure good adhesion of the insulation, but this is not essential. The pure rubber retards, but does not wholly prevent, discoloration of the tinning by uncombined sulphur present in the vulcanized portion of the insulation. Slight staining of the tin is of no importance, but heavy black stains indicate that the deposit of tin is not continuous. This is likely to produce mechanical and/or electrical failure of the insulation; a layer of separator rubber or rubber mixed with zinc oxide generally comes next, then the vulcanizing rubber, a lapping of waterproof tape being applied over this, and the whole is vulcanized into a homogeneous mass by heating in ovens.

For outer covering the cable may then be braided with hemp or jute saturated with some preservative compound usually of a tarry or waxy nature, this being the usual finish for house wires and small cables; alternatively, they may be lead covered, for protection against moisture, and armoured, for protection against mechanical injury.

Rubber insulation has been almost entirely superseded by impregnated paper for H.V. work, except for tail ends, on account of the cheapness, high dielectric strength, and low specific capacitance of the latter.

3. **Gutta percha** is similar to rubber in some respects, but it is easily distinguishable therefrom by the fact that it becomes quite soft at 150° F. It rapidly becomes brittle in air and is unable to withstand even medium voltages, so

its use is mainly confined to submarine cables for telegraphic or telephonic purposes, and the insulation of such cables should never be tested by a 500V instrument. It is rather more expensive than vulcanized rubber, and the joint insulating of gutta percha cables, which is carried out by means of a compound of gutta percha, Stockholm tar, and resin, known as Chatterton's compound, is rather a special art.

4. **Bitumen.**—The high cost of rubber cables and the search for something cheaper than rubber led to the adoption of vulcanized bitumen as an insulating covering. Besides its relative cheapness, it resists corrosion by all gases, fumes, and waters met with in practice, and it is not attacked by rats and mice, differing in this respect from rubber. Its great disadvantage is that it cannot withstand a higher temperature than 120° F. without becoming soft; consequently, if bitumen cables be even slightly overloaded, the core will sink through the insulation. Vulcanized bitumen is better than pure bitumen in this respect, but the tendency to decentralization is always present and must be carefully guarded against.

Although natural bitumen is quickly softened by contact with coal-gas and alkaline waters, this is not so with vulcanized bitumen. The latter is exceptionally inert to the action of substances of an acid character, and the action of alkaline substances on it, although existent, is superficial and so slight as to be inappreciable. Consequently, vulcanized bitumen cables are largely used in preference to lead-covered paper-insulated cables in very moist situations, such as the shafts and galleries of mines.

5. **Paper.**—Paper-insulated cables are nowadays more generally used than any others for lighting and power mains at all voltages. The outstanding feature is cheapness, but, apart from that, paper-insulated cables have a low capacitance and a high dielectric strength; these two latter properties make them specially suitable for H.V. work. The merest trace of moisture, however, will seriously lower the insulation resistance; consequently, the paper must be thoroughly impregnated with a viscous insulating oil and sheathed with a continuous waterproof covering. The oil generally used in this country is a mixture of mineral and resin oils.

The waterproof covering may consist of a vulcanized bitumen sheath, but lead is more commonly used, being applied as a solid tube under heavy hydraulic pressure. The thickness of the lead sheath varies with the size of the cable.

As in the case of vulcanized bitumen cables, paper-insulated cables are now made with the interstices between the strands of the conductor filled in with bituminous compound in order to prevent the extension of a fault, but it should be noted that a paper cable should *never be left unsealed*, even temporarily, otherwise damage is sure to result. Melted wax or tar may be used to give temporary protection to the ends, but a lead cap, wiped or soldered on, is more reliable.

Paper cables can be subjected to a greater temperature than rubber cables, and therein lies their chief merit for L.V. and M.V. work.

Size for size rubber cables and paper cables cost about the same, but the current-carrying capacity of the latter is much greater than that of the former. *See* Appendix VI.

The rating is based upon the temperatures (Fahr.) shown in the following table :—

		Rubber.	Paper.
Initial temperature		80	80
Rise of temperature		20	50
Normal maximum temperature		100	130
Maximum permissible value	Long periods	120	176
	Short periods	130	—
Normal margin of safe temperature		20	46

In situations where the initial temperature is greater than 80° F. the current rating must be reduced.

Another form of paper-insulated cable is the *dry-core* paper cable (used for telegraph and telephone work) in which the paper is lapped loosely, whether spirally, longitudinally, or both, round the single-strand conductor, and there is, consequently, a comparatively large amount of air-space. The greater the amount of air-space, the lower will be the electrostatic capacitance. The exclusion of moisture from this class of cable is of even greater importance than in the case of impregnated paper cables.

6. **Varnished cambric** (Empire tape) insulated cables occupy an intermediate position between vulcanized rubber and impregnated paper-insulated cables, as regards their tendency to absorb moisture. The tape is applied spirally to the conductor, petroleum jelly being applied to the tape during application.

Varnished cambric cables are very useful for machine and transformer connections in power and sub-stations, owing to the fact that no special precautions are necessary in sealing the ends.

7. **Silk and cotton** are used for the insulation of small wires for instrument coils, &c., the conductor being given a single or double lapping according to the class of work

for which it is required. Sometimes a coating of paraffin wax is added.

Enamel insulation is also used for similar purposes, and has the merit of being rather cheaper than the silk and cotton covering, though more liable to faults, owing to the enamel cracking.

Asbestos insulation is used for fireproof cables, but it is not altogether satisfactory because of its hygroscopic property, and also because it may serve as a wick for oil in case of switchboard fires.

38. *Protection of cables from mechanical injury.*

1. **Armouring.**—When cables are laid direct in the ground or cleated to walls, it is essential that they should be protected from mechanical injury, and this is effected by means of steel-tape or steel-wire armouring. The former constitutes the more efficient means of protection, and will stand up to the blow of a pick, but its longitudinal strength is less and it is not so flexible as the latter.

A tape armoured cable is appreciably cheaper than a wire armoured cable, unless a copper sheath is required under the lead sheath. (*See under* " Bonding and Earthing," Sec. **42**, para. 2.) In the Service the smaller power cables are provided with armouring of 15 or 16 S.W.G. galvanized steel wire, whilst the larger ones are given two layers of pickled steel tape, three- or four-hundredths of an inch in thickness. The armouring is sandwiched between two impregnated fibrous servings, one beneath to prevent the lead being pinched and the other above to protect the steel from corrosion.

2. **Tough Rubber Sheathing, sometimes called Cab-tyre sheathing,** is a form of protection for rubber cables that is now much favoured. Cables so protected are classified in the I.E.E. Wiring Regns. as *Tough rubber-compound protected cables*, and they are particularly useful where a high degree of flexibility is demanded, such as for trailing cables. The compounds used are specially selected for their toughness, flexibility, and capability of resisting rough usage, moisture, climatic variations, &c. The sheathing cannot be depended upon for electrical insulation, but it is only slightly affected by lubricating oils and almost entirely unaffected by acids and alkalis. T.R.S cables can be buried in plaster or ordinary soil without fear of deterioration.

39. *Commercial cable standards and Service cables.*

1. In the past it was the practice to designate a cable conductor by the number of strands and the S.W.G. of those strands, *e.g.*, 7/22, 3/20, and so on ; no less than 25 different

sizes of wire and 59 sizes of cable were used. The Great War plainly showed the value of standards as an aid to rapid production, and the vast effect of limiting the number of patterns and sizes so as to enable stocks to be produced and assemblies of parts to be made. At the same time, it was realized that the designation should be by dimensions (diameter or area) instead of by wire gauge, which has no international currency, and in 1919 the British Engineering Standards Association issued a new specification for insulated conductors, which recognizes 13 wires only, ranging from 0·0076 inch to 0·103 inch in diameter, and 24 sizes only of solid or stranded conductors, ranging in area from 0·001 square inch to 1 square inch. Similar reforms were made in the matter of flexible cables. Any up-to-date electrical pocket-book gives full details of these standards.

2. Commercial cables and wires are also graded according to their insulation. For rubber cables the insulation resistance per mile is always specified, and the value obtained is an indication of the quality of the rubber, but for paper cables it is not a matter of great importance, though it *is* important that their insulation resistance should be maintained. The grades of rubber cables most generally used are the 300-megohm, the 600-megohm, and the 2,500-megohm, these figures representing the minimum insulation resistance per mile. The smaller cables in each grade will have higher insulation resistances than the minimum for the grade. The use of the 300-megohm grade is not recommended. The minimum value for paper cables may be taken as 70 megohms per mile, but it should be noted that if an appreciably higher value is obtained it may indicate imperfect impregnation or a hard impregnating compound, and in either case the paper may be more brittle than it should be.

3. In the Service a nomenclature is adopted whereby a letter or pair of letters denote the class, *e.g.*, insulation, covering, protection, &c., of cable or wire, and the cross-sectional area in square inches denotes the size. Full details are given in the Vocabulary of Stores.

Cables and wires are demanded, held on charge, and accounted for as follows :—

i. All uncovered wires.	by weight.
ii. Silk- and cotton-covered wires for coil winding, &c.	
iii. Covered wires other than those mentioned in (ii).	by measurement in yards.
iv. All cables.	

The principal electric light and power cables are the J, K, and L classes.

J signifies rubber insulation. Cables of this class are listed in two grades, one called *low* (600 M Ω grade, for use up to 250V) and ***medium*** (2,500 M Ω grade, for use up to 660V). Single-core *low* and ***medium*** J cables will meet most requirements, but multicore cables suitable for any desired voltage can be demanded.

K signifies rubber-insulated and lead-covered.
KP ,, paper-insulated and lead-covered.
L ,, rubber-insulated, lead-covered, and armoured.
LP ,, paper-insulated, lead-covered, and armoured.

Single-core cables of the K and L classes are now obsolescent.

As an example, consider the cable designated *Cable, Electric, L.P.*, 0·15, 3-core, 6,600 *volts*.

This is the complete Vocabulary of Stores nomenclature for an electric cable with 3 copper cores, each of 0·15 square inch cross-sectional area, paper-insulated, lead-covered, and armoured, and suitable for a working voltage between cores of 6,600V A.C.

All insulated electric light and power cables should comply with the appropriate Government Departmental Electrical Specifications as well as with B.S.S. No. 7.

40. *Multicore cables.*

Cables with two, three, or four cores are standard commercial products, and are almost invariably used in preference to single-core cables. Although single-core lead-covered cables may be used on A.C. if the lead sheathing is lightly insulated, single-core lead-covered and armoured cables should not be used, owing to the increased inductive drop and the excessive eddy current and hysteresis losses. On D.C. two single-core cables obviously give a greater factor of safety than a twin cable, since in the latter an earth fault on one core rapidly develops into a fault between cores. This may justify the use of single-core cables in certain circumstances. As far as cost is concerned there is very little to choose between the two methods. For l.c. and a. cables with the *same conductor cross-section*, the cost of a 3-core cable may be some 10–15 per cent. less than that of three single-core cables, but the cost of a twin cable is only about 2–3 per cent. less than two single-core cables. *Compared on the basis of current-carrying capacity*, however, the multicore cables are much the more expensive, since when the conductors are bunched together, the permissible current density is much smaller (*see* Appendix VII).

Multicore cables can, of course, be obtained with circular cores, but on voltages up to 11,000, cables with segmental cores are smaller and cheaper and are, therefore, almost invariably used. The reason is that by specially shaping the cores, there is less waste space under the lead sheath, which can therefore be smaller in diameter, and the quantity of lead sheathing and armouring required is appreciably less.

Concentric cables, consisting of alternate concentric layers of conductor and insulation, are somewhat cheaper than the above types, but are now rarely used owing to the difficulty of jointing.

Special cables with any number and arrangement of cores can be obtained when required, *e.g.*, a 5-core cable is often used on a 4-wire 3-phase system, the fifth core being used as a switch wire for street lighting. Also pilot wires, or auxiliary wires for leakage and other trip gear connections are frequently laid up with the main conductor under the same lead sheath.

41. *Laying of cables.*

1. The respective merits of bare overhead line systems and underground cable systems have been discussed in Chap. III, but in spite of the increasing popularity of the former it is necessary in very many situations for the mains to be underground. No precise rules as to where these mains are to be laid can be formulated, since there are so many other things to be considered, such as telegraph and telephone routes, gas and water pipes, drains, &c. Some authorities say that, for absolute safety, cables should be at least 7 feet distant from gas and water pipes, but this is frequently impossible; 6 inches of intervening earth should normally suffice. When it is necessary to cross obstacles, such as water mains or drain pipes, circumstances will determine whether the cable should be laid under or over the obstruction. Normally, it will be better, for reasons of accessibility, for the cables to be underneath.

Before opening up any ground to lay cables the position of gas, water, and drainage services must be ascertained.

During frosty weather trench work should be suspended and all cables must be handled with especial care, as their non-metallic constituents tend to stiffen and become more or less brittle. For this reason, cables should be stored under cover in the winter; if it is necessary to keep them out of doors during a frost the drums must be covered up and kept moderately warm for at least 24 hours before handling.

The possible systems for underground mains can be grouped as follows :—

i. Cables buried direct in the ground.
ii. Cleated to walls of tunnels, &c.

iii. Cables laid solid in bitumen.
iv. Cables drawn in to ducts or pipes.
v. Bare conductors, supported intermittently on insulators in culverts or sub-ways.

System (v) can, however, be quickly dismissed. This system has been tried, but the first cost of installation is unduly high; moreover, it takes a good deal of space, and it has acquired a bad name on account of explosions. Its great advantage is that the section of copper could easily be altered so as to run at the best current density.

Joints in cables should be avoided if possible, but cable lengths are limited by the bulk and weight that can be carried on one drum, so joints will be inevitable except with small cables and comparatively short lengths.

When a joint is made in a pit, sufficient slack must be left to enable the jointed cable to be led right round the pit. Suitable iron brackets must be provided in the sides of the pit to support the joints. In the case of simple lead sleeve joints, the iron brackets should be covered with lead strip to prevent local action. These remarks apply particularly to draw-in systems, but in very wet ground it may be advisable to provide well drained brick or concrete pits for the joints in direct laid armoured cables as well. In this case, no mechanical protection for the joints is needed, but when, as is more usual, the joint in an armoured cable is made in a trench, a cast-iron box should be used. It is desirable that a little slack should be allowed on each side of the joint as it is then less liable to longitudinal tension in the event of subsidence of the soil.

When there is any suspicion that moisture may have got into the ends of a length of cable due to imperfect or damaged seals, it is advisable to allow an overlap of four or five feet, as it may be necessary to sacrifice several feet in order to make the length serviceable.

Joints must on no account be drawn into pipes or ducts.—Where practicable, the position of buried joint boxes should be indicated by stone slabs at the ground surface.

When there are several cables in the same trench, each joint box should have an identification letter legibly marked upon it.

Positions of joints should be accurately shown on the record plans.

2. Direct-laying systems.—For this method it is, of course, advisable to employ armoured cable, but, in spite of the extra cost of the armouring, the system is the cheapest as regards first cost of installation, where a comparatively small number of cables is involved.

The current carrying capacity of cables laid direct in the ground is a good deal greater than when laid in pipes (*see* Appendix VII), owing to the fact that the soil carries the heat away quicker.

Generally speaking, modern cables with their thoroughly well compounded braiding over the armouring suffer very little from corrosion, providing " made " ground, consisting largely of ashes or organic refuse, is avoided. If such ground has to be traversed for a short distance, good loamy soil must be obtained in sufficient quantity to surround the cable to a radial thickness of at least 12 inches.

There is some evidence that cables have been attacked by clay, and for this reason it is sometimes suggested that a bed of sand should be provided underneath the cable in clay soils. This practice is not recommended because the trench will then act as a drain facilitating the access of deleterious substances in solution, thus tending to make the cure worse than the disease.

The full width of the trench, not merely the centre line or one face, should be carefully marked out along the whole route before excavation is begun, in order to prevent unnecessary deviations subsequently.

All cables following the same route should be laid in the same trench.

As a general rule, the depth of trench in ordinary soil should not be less than 3 feet, except where there is no risk of injury by vehicles, when the depth may be reduced to 2 feet.

The trench should be of uniform depth and the cables must lie on even and solid ground throughout their whole length. The general line of trench should be as straight as possible, and, when there are several cables in the same trench, they should be placed as far apart as possible to minimize the mutual heating effect which tends to reduce the current carrying capacity. Crossings should be avoided.

In filling in the trench the cables should first be covered with 3 or 4 inches of fine soil, care being taken that no sharp stones come in contact with them, and then with a layer of ferro-concrete tiles or tarred planking not less than 6 inches wide to give further protection from accidental injury.

Inside forts and batteries it is often necessary to mark the line of trench on the surface in some way, as it not infrequently happens that cables are injured by pickets used as anchors and holdfasts.

When opening trenches containing cables, picks should be used as little as possible.

3. **Laying armoured cables.**—When an extended system of armoured cables is to be laid, two wheels and an axle, suitable for transporting the drums, should be provided.

The diameter of the wheels should be about 18 inches greater than that of the largest drum, and the axle should be so arranged that it can be passed through the centre of the drum and secured to the cheeks. The axle should be 2½ to 3 inches in diameter, and provided with linch pins, washers, and drag ropes, and with shafts for animal-draught if the nature of the ground is suitable for this system of transport.

Where the ground is difficult, it is generally more convenient to move the drum by manual labour, but shafts of some description will still be required for steering. Care must be taken not to bruise the cable when rolling the drum.

In order to mount the drums, they can be jacked up or run up a wooden ramp; the width of such a ramp must be such as to allow the wheels to be easily attached. The axle should be passed through and the wheels attached. To facilitate handling the drums, handspikes and scotches should be provided.

If the trench is in open ground, the cables can be laid by wheeling the drum carriage parallel to it and unwinding them at the same time. In wooded country, or where obstacles prevent the passage of the drum carriage close to the trench, it will be necessary to leave it at one end of the section, and to carry out the cable by hand.

The quickest and most satisfactory method is to carry it bodily on men's shoulders, loop by loop. The drum should be so turned that the cable is paid out from the top of the drum.

On no account whatever should the drum be taken to pieces and the cable paid out in coils, nor should any attempt be made to pay out the cable by rolling the drum along the ground.

Trenches that have been recently filled in are liable to damage by heavy rain, as the subsidence of the newly filled-in soil turns them into watercourses. This can be avoided by careful selection of routes and by judicious banking-over, but where necessary the surface must be protected by rough concrete or stone slabs.

Trenches should be carefully perambulated periodically.

When two or more lines of cables are laid in the same trench, care should be taken to preserve their relative positions so long as they continue in the same trench, *i.e.*, they should not be allowed to cross one another. Much subsequent trouble will be saved if this is strictly adhered to, and if the *relative position* of various cables is *accurately recorded* in the route diagrams.

4. Solid systems.—This method, which consists of laying the cable in suitable troughing and filling in solid with bitumen or pitch, has in the past been more used in England than any other system, though it is now giving place to direct-laying and draw-in systems. Its advantage is the complete protection of the cable from all soil electrolysis and corrosive action and the consequent freedom from breakdown. In certain soils containing large quantities of saltpetre or other active reagents, the use of a solid system may be imperative. In common with direct-laying systems, however, it possesses the disadvantage, in an even more marked degree, that extensions and additions are matters of some difficulty. Consequently, the conductors originally laid must be large enough to accommodate possible increases. Solid systems are rarely suitable for military purposes.

5. **Draw-in systems.**—Where a large number of cables is involved or where it is impossible to settle definitely the capacity at the time the cables are laid, the draw-in system, which consists of drawing lead-covered and braided cables into ducts or pipes, is undoubtedly preferable to either the direct-laying or the solid systems. In towns it is the only really practical system. The first cost may be greater for an equivalent set of cables, but in the other two systems, as has already been stated, the cables must be bigger than is necessary for immediate requirements. With draw-in systems this is not so, since the cables can easily be replaced or additional ones drawn-in to the spare ducts that have been provided. Depreciation will be less than with a solid system, because, if the latter does break down, the whole value of the mains will almost certainly be lost, whereas the cables drawn out of the ducts will have a certain value, and the ducts themselves will not be seriously damaged.

On the other hand, draw-in systems are more liable to break down than solid systems, because the cables are not so well protected from electrolytic and chemical action, and continuity of supply is consequently more uncertain.

A number of telephone cables may be drawn into one single pipe or duct, but with power cables one duct should be provided for each cable.

Stoneware conduits are the most satisfactory. They are comparatively cheap and fairly strong, and there is very little likelihood of the cables adhering to them on account of corrosion and so being difficult to withdraw. Ordinary stoneware drain pipes may be employed in lieu, and they are frequently used for telephone cables, where one line of pipes will accommodate all the cables on a particular route ; but for a number of power cables requiring one line of pipes per cable, the number of joints involved and the difficulty of building are great drawbacks. When multiple conduit cannot be obtained, it is better to use **fibre conduit**, of a size not less than 2 inches internal diameter.

Tubing, fibre, can be obtained in 5-foot straight lengths and in 22½°, 30°, and 45° bends, all of which have a plain turned spigot and socket joint.

The use of **iron pipes** is *not* recommended. They are liable to set up electrolytic action with the lead covering of cables, especially in damp situations near the sea. When a cable fails, a very bad " earth " results, and, if corrosion has taken place, it becomes rather a difficult matter to withdraw it. If iron pipes must be used, they should be made electrically continuous throughout and bonded to the lead sheath about every 220 yards.

A great drawback of ducts or pipes is their liability to act as field drains if the joints are indifferently made, and this is a point that must be carefully watched. Moreover, fibre ducts themselves are not particularly watertight.

6. **Jointing of ducts and pipes.**—For single lengths of stoneware pipes with spigot and socket ends, cement mortar (1 cement, 1 sand) is used to make the joints, and the same material is used for the joints of butt-ended multiple ducts, a mandril being placed inside each duct to prevent the cement mortar entering the duct through the joint. The Sykes conduit is supplied with jointing linings on spigots and sockets, so that a luting of Russian tallow and resin (1 to 4), applied hot just before the joint is made, is all that is necessary.

The joints of fibre tubing should be made by a wrapping of a strip of unbleached calico, 2 inches wide, dipped in hot insulating compound.

For the jointing of cast-iron pipes, see the " Water Supply Manual."

7. **Laying of ducts and pipes.**—Ducts or pipes should be laid at such a depth as not to be liable to mechanical injury by traffic. Where heavy wheeled traffic exists, stoneware and fibre pipes should not be less than 3 feet, and iron pipes not less than 2 feet, below the ground surface. If forced by an obstruction to lay above this level, some mechanical protection, such as a concrete bridge, should be given.

Ordinarily, conduits or pipes should be laid upon a bed of concrete (1 cement, 6 sand and gravel) with a 1-inch interval vertically and horizontally between single conduits. Concrete should be laid in the space between the conduits and the sides of the trench and also in the interstices between the conduits ; there should be a thin covering of concrete overall, so that the whole structure is thoroughly firm. There is then less likelihood of the joints failing and of water finding its way into the conduits. In exceptionally firm ground, where there is little or no traffic and little fear of subsidence a bedding of fine soil, with the earth well rammed down around the conduits when laid, would suffice.

Before conduits are laid, they must be examined to ascertain whether the interior is perfectly smooth ; such as have unduly rough internal surfaces should be rejected. After they are laid and jointed, each duct must be carefully scoured out with a stiff wire brush to remove any cement that may have come through the joints.

It is obviously better that all *changes of direction* should occur at draw-in boxes or manholes, and it will usually be possible to arrange for the run between boxes to be perfectly straight. If bends must be made, they should be as easy and uniform as possible. Care must be taken that a fall, suitable for drainage, is given from one box to another, or from the middle of a stretch to the box at either end. A slope of 1 in 100 will suffice. Boxes or manholes should not be more than 100 yards apart, but this figure will have to be reduced when dealing with large heavy cables.

Draw-in boxes are best made in the form of brick pits. The walls should be 9 inches thick for depths of 4 feet 6 inches and under, and 14 inches thick for depths over 4 feet 6 inches. They should be built on a cement concrete (1 cement, 1 sand, 4 aggregate) foundation, which should be 3 to 9 inches thick according to the total weight of brickwork, and should have an overlap of 6 inches all round.

Draw-in pits should be well drained and ventilated.

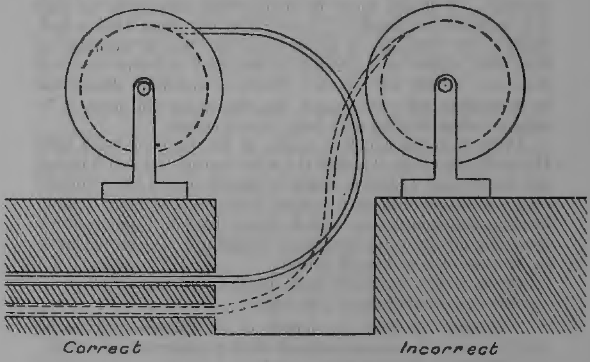
Suitable dimensions of pits are :—

Length.	3 times the length of the longest joint to be accommodated with a minimum of 4 feet.
Width.	2 to 2½ feet.
Depth.	9 inches greater than depth of lowest duct that enters.

Bell-mouthed openings, neatly rendered with cement mortar, should be provided in pits for each duct or pipe. Covers for pits may be of cast-iron or a stone slab set in a cast-iron or concrete frame, and they should be provided with suitable means for lifting.

8. **Drawing-in.**—When drawing in the cable, it is first necessary to make certain that the conduit is clean and free from all burrs and obstructions by drawing through a mop of waste and rags. Then the cable drum is jacked up at one end of the section, so that the cable, leading off the top of the drum, passes with one smooth semi-circular sweep, *not* a double bend, into the conduit (*see* Fig. 40).

With small cables less than ¾ inch in diameter, the end of the cable can be doubled back about 4 inches, and bound with primed tape to form an eye, to which to attach the drawing-in rope. With any larger cable, a steel-wire cable grip with link and swivel should be used. The lead sheath should be dressed down before the grip is fitted, so that part of the stress is borne by the conductor itself. The end by which the cable is drawn in will almost inevitably be damaged during the process, and should be cut off before the jointing or terminating is done (*see* Sec. **43**). Sacking should be placed wherever the cable is likely to be chafed, and it should be liberally lubricated with petroleum jelly as it is drawn in. For heavy cables the steady pull of a small winch is preferable to the jerky tugs of a gang of men.



Drawing Cable into ducts.

Fig. 40.

Draw-in boxes may have their covers flush with the ground surface or buried according to the depths of the ducts, but in either case the exact positions should be recorded on the site plan.

42. *General notes on cable jointing.*

Details of the jointing of power cables only are given in this chapter. For the jointing of telephone cables reference should be made to the Signal Training Manuals.

All *joints* in cables must be as mechanically and electrically perfect as possible, for they are in most cases a source of weakness in an installation.

No matter how great care is taken in the manufacture and laying of the cable, the ultimate *successful working* of the system *depends* upon the *quality* of the *joints*. A badly made joint or a badly insulated one is a source of considerable inconvenience and *danger*.

It is therefore desirable that the *whole operation*, from the cutting of the cables to the completion of the sealing, *should be carried out by one man*, who should be the best man available. The jointer's mate will have plenty to do in looking after the fire, compound, and other accessories and tools.

Take plenty of care and time over every joint. The process cannot be hurried.

1. **Types of joint.**—As " cable-jointer " is not a service trade, electricians or power linemen will be required to make cable joints, but although the majority of these tradesmen understand the principles involved, they seldom get sufficient experience to maintain a high standard of manual dexterity. Service type joints should, therefore, be of simple design, in which as little as possible is left to the skill of the jointer. Although it must be admitted that lead sleeves with plumbed joints are desirable when skilled and experienced men are available, it will generally be found that for service purposes up to 11,000 volts sufficient reliability can be ensured with simple cast-iron joint boxes, in which a good quality of " insulating " compound is relied upon for insulation and watertightness. With regard to the latter, a special " sealing " compound can be obtained, which should be used in waterlogged ground to flood all recesses in cover plates and grooves in lower half of box.

2. **Bonding and earthing.**—Both the lead sheath and armouring should be electrically continuous throughout, and well earthed. If the insulation breaks down between the conductors and the lead sheath, the danger from shock is thereby minimized.

This procedure is recommended in all circumstances, but it is legally prescribed by the E.C. Regulations for H.V. cables (650–3,000V) and for E.H.V. cables the regulations specify in addition either a sheath of copper tape not less than sixteen-thousandths of an inch in thickness under the lead sheath, or alternatively an external shield of steel wires not less than one-tenth of an inch in diameter. This requirement is necessitated because the conductivity of the lead sheath itself is not good enough to enable it to act alone as an efficient earthing connection. Generally speaking, wire armour satisfies the regulations without a copper sheath, but steel tape armour may not, owing to its relatively poor conductivity.

For cables in coal mines, an additional requirement is that the conductivity of the metallic covering (including armouring, lead sheath and copper sheath, if provided) must be at least equal to 50 per cent. of the largest conductor in the cable.

To comply with the regulations, it is clearly necessary to ensure the electrical continuity, *i.e.*, to " bond " the lead sheath, copper sheath, and armouring at all joints. It is also advisable to bond the lead sheath and the armouring together at the joints, to ensure that there shall be no difference of potential between them.

It is desirable in all cases that the conductivity of the bond should be equal to that of the lead sheath and the armouring, but the point need not be stressed except in the case of large E H.V. cables.

The best method for the lead sheath is obviously a lead sleeve, but in the simpler type of joint made in a cast-iron box without a lead sleeve, a satisfactory bond can be provided by making a good electrical connection between the lead sheath of each incoming cable and the cast-iron box itself. In L.V. and M.V. work the continuity of the armouring may be carried out through the box in the same way, but owing to the poor conductivity of the box, some engineers consider it advisable in H.V. work to add a jumper bond of tinned-copper strands not less than 0·0225 sq. in. in cross-section.

In mining work, this jumper bond is generally required in all cases, whatever the voltage.

It may not be superfluous to emphasize the necessity for care in making the electrical connection between the bond itself and the lead sheath or armouring. Steel tape armour will be found to present some difficulty in this respect.

An additional reason for bonding arises from the fact that there is always a certain amount of leakage, chiefly from consumers' premises and over " ends." Also in the neighbourhood of traction circuits, trouble is sometimes experienced from stray currents from the earth return. These leakage and stray currents, if D.C., cause electrolytic corrosion, where the current leaves the lead sheath or armouring. If current leaves the lead sheath and travels along an adjacent gas or water pipe for a distance, corrosion will take place in the latter where the current leaves it to enter the lead sheath again.

Bonding ensures a much larger surface by which these currents may enter or leave the lead sheath or armouring, and this greatly reduces the current density. It also helps leakage currents to find their way back to the power station by the metallic covering of the cable rather than by gas and water pipes in the vicinity. Further, if a considerable leakage current flows along the lead sheath (or armouring), bonds of low resistance will prevent destruction of the joint boxes due to heating, which might otherwise occur.

Generally speaking, good earth connections to substantial earth plates at each end of the cable are sufficient, but in the neighbourhood of D.C. traction circuits, additional earth connections may be advisable.

3. **Cleanliness.**—The hands, all accessories, and the exposed ends of the cable must be *clean* and *dry* before jointing is attempted.

Cleanliness is of vital importance.

Jointing should only be carried out in dry fine weather, as moisture is most detrimental to the insulation of cables. A tent or tarpaulin should always be erected over a joint pit before the cable end seals are broken, to guard against a break in the weather.

When jointing armoured cables buried direct in the ground, a sheet of canvas 6 or 8 feet square should be spread under the joint, so as to cover the bottom, sides and ledges of pit, and avoid earth getting into the box or accessories or on to the tools and stores.

The hands should always be washed after handling lead before partaking of food owing to the danger from lead poisoning. Naphtha is required for cleaning off tar, resin, &c.

4. **Preparing the ends.**—The seals on the cable ends should not be broken until all is ready to commence making the joint.

Great care must be taken to avoid damaging the insulation when removing the lead sleeve, and to avoid nicking the strands of the conductor when removing the insulation.

The end of the lead sheath where scored and ripped off for jointing should be carefully trimmed round with a knife to remove sharp edges and rough places which might damage the insulation.

When there is any suspicion that moisture has got into the cable the paper should be carefully tested by immersing samples in liquid paraffin wax or sleeve compound at a temperature of 260° F. to 280° F. when any residual moisture will be detected by the bubbles it will cause. Samples should be selected both from the layer nearest to and furthest from the conductor. Single strips only should be tested as air may be entrapped between layers and give deceptive results. Avoid touching with the hand the actual portions of paper tested.

No more of the conductor should be bared than will make a satisfactory conductor joint. This is to keep down the cost of insulating material and to keep up the insulation resistance of the joint, which is less the longer the joint.

With rubber cables, as has been explained in Sec. 37, para. 2, perfect tinning is of the utmost importance. The tinned surface of the conductor should not be scratched or damaged in any way, and, when using a file or pair of pliers on a joint, care should be taken to see that no copper is left untinned. No india-rubber solution must be allowed to come into contact with the bare wires, and such solution should be used sparingly.

If resin oil has been used for the impregnation, no cleaning or tinning of the conductors is required when soldering. Other impregnations may require the conductors to be separated and cleaned with naphtha.

Emery cloth should not be used for cleaning conductors, as the metallic dust may be the cause of earthing troubles.

Lead surfaces must be thoroughly scraped and cleaned before soldering, otherwise the joint will not be airtight, and damp will get in sooner or later. The scraped surface of the lead should be coated with tallow at once to facilitate the subsequent soldering.

5. **Testing.**—It is always desirable, where possible, to measure and record the C.R. and I.R. of each length of cable just before jointing is commenced.

6. **Solder and soldering irons.**—Soldering irons should never be allowed to get too hot and " burn." This always gives rise to an excessive lurid green flame, and is not only injurious to the " copper bit," but burns all the tinning off, thereby giving extra labour and wasting time in re-tinning. Irons may be cleaned with emery cloth, or carefully with a suitable file ; they should be *well tinned*, and hot enough when used to be unbearable when placed about 1½ inches from the cheek. The irons should be wiped when taken out of the fire before applying to the joint.

Quick soldering is essential, as continued application of heat seriously weakens copper wire and makes it brittle. Also too great a heat causes solder to " rot " and become useless. Too much attention cannot be paid to the soldering irons. It is perfectly hopeless to attempt to solder a joint with a dirty iron, a badly tinned iron, or an iron that is not hot enough.

Solder should be in thin sticks, and should contain enough tin to enable one to hear it crinkle when bent double close to the ear. (Correct proportion for tinman's solder is 1 tin 1 lead. Plumber's solder which is used for wiped joints is 1 tin 2 lead.)

7. **Flux.**—Resin only may be used as a flux, preferably in the powdered form. If its use in this way presents difficulty, it may be dissolved in methylated spirit and applied with a

small mop. All liquid fluxes and other *substances* (*e.g.*, hydrochloric or muriatic acid) containing *corrosive* ingredients, *must not be used on any account.*

8. Brazing lamps and blow lamps.—The following service types may be used for cable jointing: (1) *Lamps, brazing,* 1 *pint ;* (2) *Lamps, spirit, blow-pipe.*

The brazing lamp (sometimes called a blow lamp) consists of a vessel containing paraffin which is ejected at the burning nozzle in the form of a fine gaseous spray. The ejection pressure is provided by a small air pump which is incorporated in the lamp.

The container must never be more than three-quarters filled. The remaining space is required as a reservoir of air under pressure. Neither crude oil, dirty paraffin, nor petrol must be used.

On its way from the container to the nozzle, the liquid passes through a coil of copper tube known as the " burner," the object of which is to heat the oil to as near vaporizing temperature as possible. To heat up this coil at starting, a little cotton waste or yarn soaked in paraffin or methylated spirit is placed in a small receptacle below it, ignited and allowed to burn for three or four minutes. During this period the *air valve must be open.* When it is thought that the burner is hot enough, close the air valve and give the pump a few rapid strokes. If the lamp flares up, it indicates that the burner is not yet hot enough ; the air valve should be opened again, and the external heating continued.

When hot enough, the gases issuing from the nozzle burn with a fierce blue flame.

It is very important not to pump up and try to use the lamp before the coil has been heated sufficiently. Neglect of this precaution is one of the most fruitful causes of failure of blow lamps due to the choking up of the interior of the burner with carbonized oil.

The air valve and pump washer and packing will require renewing occasionally.

The fine hole in the nipple will require frequent cleaning. This is done with a fine steel wire pricker, specially provided for the purpose. Great care must be taken in this operation, as if the nozzle becomes enlarged the lamp is useless.

In another type of blow lamp which is sometimes met with, methylated spirit is used instead of paraffin, and a pump is therefore unnecessary, the vapour pressure of the liquid itself being sufficient.

The *lamp, spirit, blow-pipe* consists of a small vessel containing about ½ pint of methylated spirit which burns at a wick passing through the top. Attached to the vessel is a curved pipe with an aluminium mouthpiece at one end and a length of rubber tubing at the other. When the lamp is not in use the cap should always be replaced, otherwise the cotton wick will get wet and the lamp will not burn properly.

9. **Notes on sleeve and box compounds.**—For terminating boxes and low voltage joint boxes, modern practice favours the use of an insulating compound which is, in effect, " solid " at ordinary temperatures, but sufficiently fluid to avoid brittleness at freezing temperatures, and sufficiently plastic to avoid leakage from the box or into the cable under the maximum temperature conditions obtaining in practice. High-grade solid box compounds are very stable in their properties and adhere well to the box and to the jointed conductor. They possess very high dielectric strength, but their great disadvantage is the considerable shrinkage which takes place on cooling (of the order of 9–10 per cent.), and the liability for blow-holes or air pockets to form in their mass. Moreover, when the cable warms up there is a tendency towards " breathing " of the impregnating oil into and out of the joint. The warm oil has a solvent action on pitch which is the basis of most solid compounds, and the mixture has relatively bad electrical properties. For H.V. joints, therefore (and for lead sleeve joints at all voltages), it is preferable to use a resinous compound, which has the consistency of vaseline at ordinary temperatures and runs as freely as heated oil at the pouring temperature. This type of compound approximates more closely to the cable impregnation, it penetrates all the crevices in the joint and box more thoroughly, and its consistency is such that cracks and air pockets cannot form.

For sealing the glands, the tongued and grooved joints between the upper and lower halves of cast-iron boxes, and the wells above the filling holes, a so-called " *sealing* " compound may be used. This is a waterproof compound of a cement-like nature, having very good adhesive properties. Its electrical properties are quite as good as those of the solid insulating compound, but it is relatively expensive.

The solid insulating compound is very little inferior for sealing purposes in ordinary circumstances, but in waterlogged ground the sealing compound should be used.

All these compounds are non-hygroscopic.

10. **Filling boxes and lead sleeves with compound.**—This operation requires more care and skill than is usually supposed.

It is important not to heat the compound more than is absolutely necessary to secure the required fluidity, otherwise the insulating properties might be impaired.

Consequently it is important that the compound should not lose too much heat during the filling process. If a ladle is used it should be placed in the compound while on the fire for half a minute or so before pouring. If the compound is poured direct from the melting pan into a funnel, the latter should be heated with blow lamp previous to pouring. The box itself should be well heated with blow lamp before filling. Do not pour the compound too quickly or air may be entrapped. One plug hole must always be available as an air vent. If these precautions are not taken, the compound may solidify before all the air has been forced out of the nooks and crannies of the box.

As the compound cools it contracts, and it will be necessary to keep some compound hot and top up about three times at intervals (say) of 10 minutes. Plugs may then be screwed home temporarily and left until the following day, when the box should again be examined, and given a final topping up if necessary.

It is very essential that the box should be *completely* filled with compound, as it is quite certain that any air space left will, sooner or later, get filled with water.

(Pole-type terminating boxes are an exception to this rule. These should not be topped up after filling, owing to the expansion of the compound which occurs in a hot sun.)

43. *Details of jointing.*

1. Single-core cables will first be considered.

Conductor joints.—These should be such that their conductivity is at least equal to that of an equivalent length of the conductor; they are most easily made by means of a *tinned copper sleeve*, into which the ends of the cables to be jointed are butted, and the whole is then sweated up. The sleeve joint is to be considered the standard conductor joint, but, if the correct size of sleeve (*see* Table E), or the material from which it can be constructed locally, is not available, then a *twist joint* for single-strand and 3-strand conductors, or a *married joint* for 7-strand conductors, may be employed. For 19-strand and 37-strand conductors the sleeve joint should always be employed.

In the subjoined instructions for the making of these joints, it is assumed that lead-covered cable is being dealt with. These instructions can readily be adapted for the making of joints in J class cables.

Sleeve joint.—*To make the sleeve* :—Take a piece of sheet copper (for dimensions *see* Table E), and clean it thoroughly.

Bend it round a mandril (for diameter *see* Table E) to form a split-tube.

Drill two holes, one at each end, ⅛ inch in diameter diametrically opposite the slot at a distance of ⅛ to ⅜ inch from the end.

Clean the split-tube inside and out and also at the ends and slot, and cover it with a thin coat of pure tallow.

Roll the split-tube in finely powdered resin, and dip it into a pot of molten solder. Whilst hot, wipe the inside and outside with a rag to remove superfluous solder. For wiping the inside, a pull-through, consisting of a piece of wire bent double with pieces of rag secured in the bight, should be used.

If preferred, the sheet may be tinned when flat, and then formed into a sleeve.

Weak-back Ferrule.—This type of ferrule has a longitudinal groove diametrically opposite the slit, which is made wide enough to slip over the conductor ends when they are butted together.

The groove weakens the ferrule sufficiently to permit it to be closed up with pliers around the conductor, a final grip being applied just before the solder solidifies. This design has the advantage that no undue bending of the paper-insulated cores is necessary—unless very carefully done this is liable to fracture the insulation, particularly at the crutch in multicore cables.

It is not essential, of course, to bend the cores to get the ordinary copper sleeve into position, but twice the required length of insulation has otherwise to be removed on one side to allow the sleeve to slide over for its whole length. This should be avoided in the case of H.V. taped joints, as it makes a longer joint and requires more taping.

To prepare the ends of the cable :—

Score the lead sheath all round through about two-thirds of its thickness at a distance from the end 1½ inches greater than half the length of the copper jointing sleeve (*see* Table **E**).

Lengthwise from the score to the end of the cable, using hack knife and hammer, make a slanting cut in the lead sheath, and then tear it off. Great care must be taken not to damage the core insulation. It is advisable in the case of paper cables to warm the end slightly to soften the impregnation.

With paper-insulated cables, tie down the insulating paper round the conductor with 3 or 4 strands of thread at a distance of 1¼ inches from the ends of the lead sheath.

Bare the conductors for a distance ¼ inch greater than half the length of the copper jointing sleeve (*see* Table **E**), and clean the outer strands (if stranded), without disturbing the lay, with naphtha. If the cable is not in good condition, it will be necessary to unlay, clean, re-tin (if rubber-insulated), and relay the outer strands.

Protect the remaining 1¼ inches of insulation by a few layers of tape.

Secure the outer strands (if stranded) with two turns of binding wire, whilst a few turns of tinned-copper binding wire (*Wire, jointing and binding, AA* 13) are placed in position near the end.

Remove the first binding wire, and solder solid by means of a soldering iron, by a pot of molten solder, or by pouring solder from one ladle to another. Powdered resin only may be used as a flux.

Remove the second binding, and file the ends up square.

To make the joint :—

From a piece of lead piping of suitable size (*see* Table **E**) cut off the length required for the lead sleeve and prepare a filling hole at the centre in the following manner :—

Drill a ¼ inch hole. Then beat up the lead so that the finished hole has a lip rising like a crater from the top of the sleeve. The height of the crater will depend upon the size of the hole, but with a 1 inch diameter hole a crater wall ¼ inch to ⅜ inch high can be obtained, which is sufficient.

Alternatively the hole can be enlarged to the required size with a hack knife, and a short length of lead tube soldered on at right angles to the sleeve.

The diameter of the filling hole should be as large as possible, but not greater than one half the diameter of the lead sleeve.

Drill two small holes, one at each end, and about one inch from the ends, to act as air vents.

It may be noted here that in high voltage work where it is vitally important that no air space shall be left in the lead sleeve, it is usual to provide two filling holes, one near each end of the sleeve, to ensure that the compound level will be well above the interior of the sleeve.

In this case one hole is used at a time for filling, and the other acts as a vent hole.

If the exact size of lead piping is not available, the next larger size can be used, provided that the joint box will accommodate it, and leave space (⅛ inch minimum) for compound, or a smaller size can be enlarged by driving cone-shaped hardwood mandrils through it. (It will be found that this does not reduce the thickness of the lead, though a slight shortening will take place and should be allowed for.)

Clean the ends of the sleeve, and scrape the outer edges and also slightly inside the ends. If this is not done, the solder will not take.

Thoroughly clean the lead sheath of each cable for about 2 inches from the end by scraping with a knife.

Pass the sleeve over the end of one cable.

Insert the conductor ends, prepared as described, into the split tinned-copper sleeve, made as described. The sleeve should be a close fit, and, if the ends of the cable do not butt exactly square, they should be filed until they do.

For cables under 19-*strand*, take resin-cored solder, if available, coil it round two fingers, letting the end project about 6 inches, and with a soldering iron run the joint with solder along the split. Apply the least amount of heat that will make the solder run.

For cables 19-*strand and over*, pour molten solder from a small ladle into the split, the small ladle being replenished from a large ladle, which is also held underneath the joint to catch any drips. In carrying out this operation, the joints should be kept perfectly level, and the pouring of molten solder should cease when it runs from the small holes near the end of the sleeve.

All superfluous solder should be wiped from the completed joint, which should be allowed to cool gradually.

Just before the solder has set squeeze the copper sleeve as tightly as possible on to the conductor with a pair of gas pliers.

In order to prevent damage to the insulation, the soldering process should not be permitted to take more than half a minute.

Twist joint.—As already stated, this is an alternative to a sleeve joint for single-strand and three-strand conductors.

Remove the lead sheath from the end of each cable or wire for 3 inches, as described for a *sleeve joint*.

Prepare a lead sleeve, as described for a *sleeve joint*, and pass it over the end of the cable.

With paper-insulated cables, tie down the insulating paper round the conductor with 3 or 4 strands of thread at a distance of 1 inch from the end of the lead sheath.

Bare 2 inches of the conductors, and clean thoroughly with naphtha.

Place the two wires across each other, the crossing point being the middle of the bared part.

Grip the crossing point with pliers, and twist one of the free ends round the standing part of the other wire. Do the same with the other, straighten the joint, and trim up the ends, taking care that no projecting end is left.

With a soldering iron run the joint with solder, taking care to apply only just sufficient heat and for as short a time as possible.

Smooth over the joint, if necessary, with a file, taking great care not to leave any portion untinned in rubber insulated cables.

Married joint.—As already stated, this is an alternative to a sleeve joint for 7-strand conductors.

Remove the lead sheath from the end of each cable for about 6 inches, as described for a *sleeve joint.*

Prepare a lead sleeve, as described for a *sleeve joint,* and pass it over the end of one cable.

With paper-insulated cables, tie down the insulating paper round the conductor with 3 or 4 strands of thread at a distance of 1 inch from the end of the lead sheath.

Bare 5 inches of each conductor, unlay, clean with naphtha, and straighten each strand.

Cut off 3½ inches of the centre strand of each conductor.

Lay up the strands again as far as the end of the centre strand, and splay the six ends in the form of a cone.

Marry the two splayed ends, and twist the six strands of one conductor, one by one, round the other conductor against the lay of the standing part, taking care that they do not override. Repeat this operation with the other conductor.

Tighten up with the pliers, and see that no ends project.

With a soldering iron run the joint with solder, taking care to apply only just sufficient heat and for as short a time as possible.

2. **Insulating joints.**—The insulation of joints is effected by means of india-rubber tape (*Tape, rubber, pure*) and solution (*Solution, rubber*) in the case of rubber-insulated cables, and impregnated cotton tape (*Tape, cotton, impregnated, ⅞-inch*) in the case of paper-insulated cables.

Rubber-insulated cables.—India-rubber tape is issued in tins containing 2 ozs., and india-rubber solution in 3-oz. collapsible tubes and 1-lb. tins. The tins or tubes should never be left open, and great care should be taken to prevent water getting into them.

India-rubber tape should be cut from the roll diagonally, and in lengths not greater than 9 to 12 inches.

It should be stretched gradually and perfectly evenly; if it has been in stock for some time it is well to warm it slightly before stretching it, say by keeping it in the pocket for a while. Care must be taken not to overdo the stretching so as to cause the tape to lose its elasticity. Should this inadvertently be done it can be restored to its normal condition by warming it again slightly. Tape which is too old to stretch evenly, or presents a hard cracked surface or is soft and inelastic, should not be used.

The most important point in insulating a joint or the end of a rubber cable is to lay the tape serving over the insulating material in such a manner as to cause it to unite perfectly, both on the tapered portion and beyond the taper. Care must be taken that the serving is commenced on the bare wires and not on the tapered part of the insulating material, and that the serving should only just overlap the insulating material before commencing to use india-rubber solution; the solution should not come in contact with the bare wires.

Rubber solution should be *very sparingly* used.

It is a good plan to use solely the tip of the third finger of the right hand to apply the solution, and keep the other fingers as free from solution as possible.

The operation is performed as follows :—

Cut away any insulation damaged during the soldering operation. Bare the insulation for about 1¼ inches on each side of the joint by removing the tape or other protective covering. Scrape the rubber lightly, and remove all threads and dirt, taking great care not to cut the rubber. Trim the ends of the rubber to a taper about ½ inch long using curved jointer's scissors, the pure rubber, if possible, being just exposed at the bottom of the taper. The tapers must on no account be exposed to the air for a longer time than is necessary, and must be kept scrupulously clean and dry; if by any means they become in the least dirty, they must be wiped over with a piece of clean rag, which should be free from fluff and damped with naphtha.

Commence serving with india-rubber tape on the bare wire just beyond the point of the tapered portion of the insulating material, and wind first over the bare wire and copper sleeve, using no solution. Each turn should overlap the preceding turn by half its width. As soon as the bare wire and sleeve are covered, apply a little india-rubber solution to both sides of the tape and also to the insulating material, and continue the serving up the tapered part and for a further distance of ½ inch. Then serve back over the joint, continuing to use a little india-rubber solution; carry the serving over the tapered portion of the insulating material, and for a further distance of ½ inch on the other side of the joint. Then serve again over the joint, now carrying the serving to the top of the taper on the other side of the joint. On reaching this point, serve back again over the joint to the top of the other taper.

After this, continue the serving forwards and backwards, always using solution, until the tape is served up to a thickness at least equal to that of the rubber insulation on the cable itself.

Paper-insulated cables.—Impregnated cotton tape is issued in 8-oz. tins. It should be kept in its tin until required for use, when it should be suspended in hot sleeve compound at a temperature of about 230° F., until all bubbling has ceased. Care must be taken that the tape does not touch the metal sides of the containing vessel, and it should not be removed from the compound until it has cooled sufficiently to be handled with ease.

When applying the tape it should be drawn as tightly as possible *at every turn* in order to exclude air. (This is of the utmost importance in H.V. cables.) Each lap should overlap the preceding one by half its width.

After the conductor joint has cooled and the protecting tape has been removed, the core insulation must be tapered in H.V. cables for a distance of from 1½ to 3 inches, depending upon the voltage and size of conductor. (This operation is not necessary on L.V. and M.V. cables.) The tapering may conveniently be done as follows :—With a length of 26 S.W.G. tinned copper wire, take a turn round the core insulation at the required distance from the end and remove the top layer of paper up to this point. Then take a second turn (say one-tenth of an inch) nearer the end and remove the second layer of paper, and so on.

The joint is now covered with impregnated cotton tape to a thickness of 1½ times (twice for H.V.) that of the paper insulation on the cable, tapering the tape over the core insulation to within half an inch of the lead sleeve.

At each second layer of insulating tape and again finally before putting on the lead sleeve, the joint should be basted with sleeve compound at a temperature not exceeding 250° F.

The lead sleeve should be capable of passing quite easily over the joint.

3. **Jointing of lead sleeves.**—After the conductor joints have been made and insulated as described in paras. 1 and 2, the jointing and filling with compound of the lead sleeve must be proceeded with.

Assuming that the lead sleeve has been properly cleaned and has been slipped over the cable before the conductors were jointed, and that the lead sheath has been cleaned as described for a sleeve joint in para. 1, the ends may be jointed by either of the following methods :—

(i.) *Wiped joints.*—If a skilled plumber-jointer is available.
(ii.) *Soldered joints*, using ordinary tinman's solder and a blow-lamp or soldering iron.
(iii.) *Amalgaline plumbing.*

For (ii.) *Soldered joints*, the procedure is as follows :—Slip the lead sleeve back over the insulated joint, and dress down its ends carefully around the cable, taking care that the filling hole is on top.

Caulk the ends of the sleeve with dry clean lamp cotton or cotton waste, $\frac{1}{16}$ inch from the ends ; otherwise more solder will be required than is necessary. Rags must not be used for caulking, as they are not sufficiently pliable.

Take a blow-lamp (*Lamp, spirit, blow-pipe*), fill it three-quarters full with methylated spirit, and adjust the end of the blow-pipe in the wick to give a blow-flame about 2 inches long.

Take resin-cored solder (*Solder, No.* 6), and coil it round two fingers, letting the end project about 6 inches. Blow the flame lightly round the lead sleeve and cable to warm them, keeping the lamp as nearly as possible vertical and 1½ inches from the joint.

Only the tip of the blow-flame should play on the lead. Lay the solder lightly on the joint, and blow on the solder, not on the lead.

Let the solder lie in rough lumps at first, as this warms the joint.

Continue right round the joint.

Finish off by starting at one place, and blow all round without adding fresh solder, taking care not to set up too much heat at any one spot.

Go round the edges with solder, and make sure that the joint is good everywhere.

Whilst still warm, rub the joint with tallow or a glycerine and soft-soap solution. This will show up any pinholes, which can be sealed up with a touch of solder. The under side of the joint can be examined with the aid of a mirror.

If the solder does not take everywhere, it shows that the lead surfaces have not been thoroughly scraped and cleaned.

Sweat up the other end of the sleeve in a similar manner.

The sweating up of the lead sleeve joints can be done by means of a soldering iron, but the above method is more reliable.

(iii) *Amalgaline plumbing.*—This method is much quicker and neater than soldering.

The surfaces must be thoroughly well cleaned as for other methods. Then a piece of amalgaline ribbon is wrapped round the lead sheath, and the sleeve is dressed down carefully until it fits closely on to the ribbon. The surfaces must be kept in close contact whilst heat is applied by means of a blow-lamp until the ribbon melts. When this occurs, the two opposing lead surfaces fuse and run together, and the joint is completed.

To fill the sleeve with compound, place the joint in a horizontal position with the filling hole uppermost.

4. **Filling sleeve with compound.**—Melt some compound in a suitable pan or ladle with a lip for pouring.

Heat up the lead sleeve with a blow-lamp (*Lamp, spirit, blow-pipe*, or *Lamp, brazing, 1 pint*, according to size of cable),

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JOINTING POWER CABLES. (See Section 43.)

Large Box for all power cables over ⅞" dia. over lead sheath.		Small Box for all power cables up to ⅞" dia. over lead sheath.	
A	3⅛"	A	1⅞"
B	3⅝"	B	2⅜"
C	2⅛"	C	1⅜"
D	1⅝"	D	.⅞"
E	2⅜"	E	1⅝"
F	2½"	F	2"
G	2"	G	1½"
ℓ	10"	ℓ	10"
λ	11"	λ	11"
L	15"	L	14"

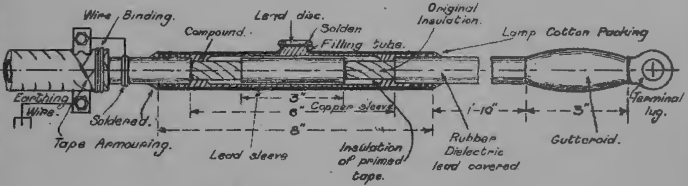

Fig. 1.

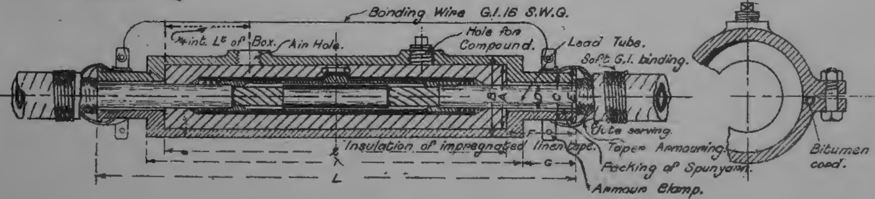

Fig. 2.

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taking care not to melt the soldered joints at either end or the joint round the shoulder of the filling tube, and keep it hot while the compound is being poured in ; otherwise the compound will solidify and settle into a solid block, thus preventing a complete compounding of the joint.

A suitable thermometer should always be used to test the temperature of the compound before pouring, as this is a highly important matter. The insulating qualities of the compound will deteriorate with overheating and air-bubbles may be formed inside the sleeve. The correct pouring temperature varies slightly with the composition of the compound and care should be taken to ascertain the correct figure for the particular compound employed. If no data are available, the figure of 250° F. may be assumed.

Pour in the compound until it appears in both air-vents, filling up till flush with the top of the filling hole.

Allow the sleeve to cool down until it is possible to hold the hand on it, and then pour in more compound to compensate for shrinkage.

Seal the filling hole by soldering on a lead disc.

Seal the air-vents with drops of solder.

Clean off any compound spilt over the sleeve by rubbing it with tallow and rag.

It may be noted that the joints of lead-covered cables may be effected without the use of lead sleeves at all, provided that a suitable joint box is used and that care is taken to bond the sheathing through, reliance being placed upon the compound with which the box is filled for the exclusion of moisture. The details of this method will be dealt with later when considering the jointing of multicore cables. With unarmoured cables, however, the use of a lead sleeve means a great saving in space, in the quantity of insulating compound used, and in the gross weight of the joint ; moreover, separate bonding is unnecessary.

5. Fixing cast-iron joint box.—In the case of armoured cables laid in trenches the lead sleeve joint made as described above should be protected in a cast-iron box.

The only service type of box, known as a "*Box, joint, cable, armour grip*" and suitable for single-core cables only, is now obsolescent, but as this type of box may be met with for some years, the procedure for utilizing it is given in the following (*see* Pl. **55**, Fig. 2) :—

Pass the lead sleeve over one end of the cable. If it is not large enough to go over the armouring, the latter must be unlaid for a short distance.

Complete conductor and lead sleeve joints in the manner described above.

TABLE E.—*Sleeve joints in single-core 660-volt power cables.*

Cross-sectional area of conductor. 1.	Number of strands and diameter in inches. 2.	Detail for local construction of split tinned-copper sleeves for conductor joints.				Lead sleeves (from existing stock or cut off from lead piping).			Tape.	
		Copper sheet.			Maximum diam. of mandril. 6.	Minimum thickness. 7.	Length. 8.	Internal diam. 9.	Rubber, pure, for rubber cables. 10.	Cotton, impregnated, for paper cables. 11.
		Gauge. 3.	Length 4.	Width. 5.						
Sq. in.		S.W.G.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ft.	Ft.
0·0045	7/·029	16	1·0	3/16	0·085	1/16	7	1	1	2
0·007	7/·036	16	1·0	1/4	0·105	1/16	7	1	1	2½
0·010	7/·044	16	1·0	5/16	0·13	1/16	7	1	1	3
0·0145	7/·052	16	1·0	3/8	0·15	1/16	7	1	1	3½
0·0225	7/·064	16	1·5	1/2	0·19	1/16	8	1	1½	4½
0·040	19/·052	16	1·5	3/4	0·26	1/16	8	1	1½	5½
0·060	19/·064	16	1·5	15/16	0·32	3/32	8	1	2	6½
0·075	19/·072	13	2·0	1	0·36	3/32	8	1¼	3	7½
0·100	19/·083	13	2·0	1 3/16	0·41	3/32	8	1¼	3½	8
0·120	37/·064	13	2·0	1 5/16	0·44	3/32	8	1¼	4	8½
0·150	37/·072	13	2·5	1½	0·50	3/32	9	1¼	5	10½
0·200	37/·083	13	2·5	1¾	0·58	3/32	9	1½	8	14½
0·250	37/·093	13	3·0	1⅞	0·65	⅛	9	1½	13	21
0·300	37/·103	13	3·0	2⅛	0·72	⅛	9	1½	16	26
0·400	61/·093	13	3·5	2½	0·83	⅛	10	2	19	31½
0·500	61/·103	8	4·0	2¾	0·92	⅛	10	2	22	37½
0·600	91/·093	8	4·0	3⅛	1·02	⅛	10	2	23	39
0·750	91/·103	8	4·5	3⅜	1·13	⅛	11	2½	25	42
1·000	127/·103	8	5·0	4⅛	1·33	⅛	11	2½	31	62

NOTE.—If copper tubing of approximately the correct dimensions is available it can be used for the split tinned-copper sleeve in lieu of sheet copper.

Relay the armouring, if it has been removed, to within three inches of the lead sleeve.

Bind a few turns of binding wire round each cable at a point which will be just clear of the ends of the box, and cut off the armouring at a point 3 inches from these bindings.

Place the finished joint in position in the bottom half of the box, and fit the upper half of the box in position, making the joint with *Tubing, lead, ⅜-in.*; if the lead sheath is smaller than the interior of the nozzle, pack it round with spun yarn or other suitable material to keep the compound in the box, taking care that it is not pressed on the lead sheath hard enough to damage the sheath.

Clean the armouring, and fit it over the nozzles of the box. With tape armouring, take a complete turn with the upper tape and a lesser one with the lower, so that they overlap as far as possible. With wire armouring, space the wires evenly round the nozzle. In either case, clamp the armouring firmly to the nozzle by means of an armour clamp.

Connect the two clamps by a bonding of tinned copper wire of at least 0·0225 sq. in. in cross-sectional area outside the box to ensure the electrical continuity of the armouring.

Melt about 5 lb. of compound in a *Pot, melting, 3 pints*, to a temperature not exceeding 250° F. Special care must be taken that the compound does not boil over and catch fire.

Unscrew the two plugs in the cover of the box, and warm the box by means of a *Lamp, brazing, 1 pint*.

Pour the compound in through one of the plug holes by means of a *Ladle, melting, 1 pint*, air escaping through the other plug hole.

Whilst cooling, the compound will naturally contract and this contraction may continue for several hours. It is necessary, therefore, to top up at both plug holes after about 10 minutes and again at the end of half an hour before first screwing home the plugs. Finally, the plugs should be removed after about 12 hours and, if necessary, the box should again be topped up.

Tape-armoured cables will not stand much longitudinal strain, and, in any case, it is advisable to leave a certain amount of slack on each side of the box by laying the cable in the form of a S.

If the joint is not made in a pit, and if some form of cast-iron box is not available, the cables, if wire-armoured, can be spliced, care being taken to preserve the electrical continuity of the armour by utilization of armour clamps.

If the cable is tape-armoured, a short length of cast-iron pipe, passed over the cable before the joint is made and then slipped back over the joint, forms a suitable mechanical protection; but any strain on the cable will, of course, strain the lead sleeve joint, and the method is not suitable for climates with large changes of temperature. Strain on the sleeve joint can, however, be to a certain extent avoided by sealing up the ends of the pipe with spun yarn and finishing off with a wiping of cement; additional security can be obtained by tapping the pipe for two plugs and filling with compound, thus converting the pipe into an improvised box. Again, care must be taken to preserve the electrical continuity of the armour by bonding over the completed joint.

6. **Jointing of multicore cables.**—The detailed instructions given in paras. 1 to 5 for the jointing of single-core lead-covered and armoured cables can readily be adapted for the jointing of multicore cables. But it is now universally recognized that the time and expense involved in making taped joints in lead sleeves are not justified in L.V. and M.V. distribution work up to 660 volts. The conductor joints made as described above can be satisfactorily insulated and protected in a cast-iron box involving very simple operations. This method of jointing has been used extensively on the continent for many years on cables up to 20,000 volts, but it is not so popular in Great Britain above 660 volts; the taped lead sleeve joint being considered the best practice, as it approximates more closely to the actual cable construction.

For service purposes, however, it may be taken that when ordinary care is exercised, satisfactory straight-through joints can be made in roomy cast-iron boxes, without lead sleeves, on cables up to 11,000 volts.

Pl. **56** shows a type of box that leaves as little as possible to the skill (or rather the manual dexterity as distinguished from ordinary care and common sense) of the jointer.

High-grade box compounds are relied upon for insulation and watertightness. The conductor joints are not taped, but porcelain spreaders are employed to maintain adequate clearances between the cores.

The conductor connecting sleeves are fitted with a number of pointed steel grub-screws rendering a soldered joint really unnecessary, but when time permits the joints should be soldered as well.

A large manhole provided in the upper half of the box permits inspection of the completed joint and facilitates filling with compound direct from the bucket.

The following figures will give some idea of the weight and dimensions of these boxes :—

660 *volt, suitable for three cores,* 0·1 *to* 0·15 *sq. in.; or four cores,* 0·075 to 0·12 sq. in. :—overall dimensions 25″ × 8″ × 7½″, weight of box 44 lb., weight of compound, insulating 8 lb., sealing 1 lb.

PLATE 56.

CAST-IRON STRAIGHT THROUGH AND BRANCH JOINT BOXES.

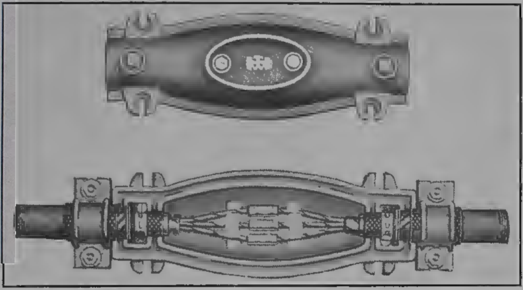

Fig. 1.

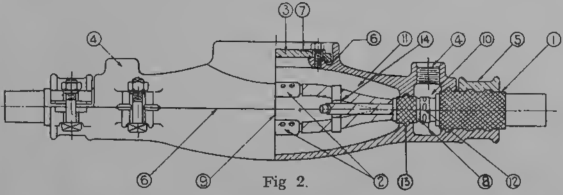

Fig 2.

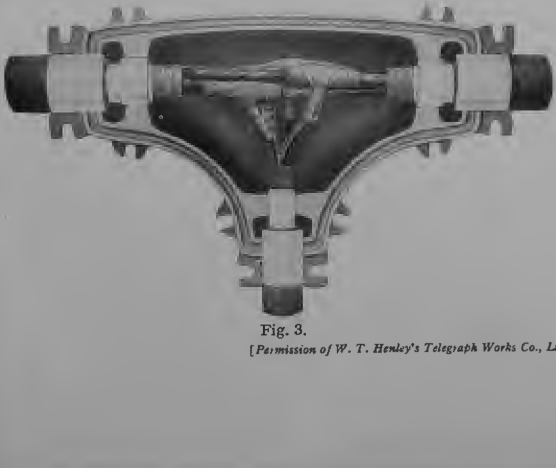

Fig. 3.

[Permission of W. T. Henley's Telegraph Works Co., Ltd.

6,600 *volt, suitable for three cores* 0·0225 *to* 0·06 *sq. in.* :—overall dimensions 30″ × 8″ × 8″, weight of box 51 lb., weight of compound, insulating 11½ lb., sealing 1 lb.

7. Instructions for making a straight-through joint in a 3-core, 3,300-volts, 0·0225-sq.-in., paper-insulated, lead-covered and armoured cable, using Henley's cast-iron joint box. (Numbers refer to Pl. **56**.)

(*a*) *Square up ends of cable.*—Mark cutting points, allowing about 1 inch overlap, bind with a few turns of G.I. wire, and cut ends off square with hack-saw.

(*b*) *Remove armouring.*—Bind armouring of each cable with about 6 turns of 16 S.W.G. G.I. wire at a point 8 inches from the end (*i.e.*, at inner end of armour clamp) and remove armouring up to this point. A triangular file should be used for this purpose.

(*c*) *Remove lead sheath* (8).—Cut off 5 inches from each end.

(*d*) *Remove insulation.*—Remove the outer paper sheath of each cable up to 1 inch from lead sheath and then bare the conductor for 1 inch. Protect the exposed paper insulation (from moisture, heat and solder) by a few layers of dry impregnated cotton tape.

(*e*) *Joint conductors.*—Sweat ends of conductors solid and insert them into the tinned brass connectors (2), care being taken that the ends meet squarely at the centre of the connector. Tighten up the grub screws and solder. The protecting tape can then be removed.

(*f*) *Put on lead bonding strips* (12).—The perforated tinned-copper bonding strips are soldered on to the lead sheaths at the appropriate points, care being taken to scrape the lead bright under the strips, which are given complete turns around the lead sheaths.

(*g*) *Put on gland packings.*—

(i) Bind the compounded canvas tape (13) over the lead sheath of each cable at the appropriate points until the overall diameter is slightly more than the internal diameter of the inner gland, each turn being warmed during wrapping by a blow-lamp to ensure adhesion between layers.

(ii) Thoroughly clean the outer surface of the armouring of each cable where it will be gripped in the box and bind with lead strip $\frac{1}{16}$ inch thick (1) until the overall diameter is slightly more than the internal diameter of the armour clamp.

(*h*) *Place porcelain spreaders* (14) *in position.*—These should previously have been immersed in hot compound to ensure that they are quite dry

(*i*) *Secure joint in box.*—Place bottom half of box under the joint and bolt up the armour clamps (5). The insides of the armour clamps must be well cleaned so as to ensure a good electrical contact between the lead strip and the box. Then connect the lead bonding strip to the box by the studs provided. The contact surfaces under the strips on the box must be well cleaned.

Warm bottom half of box with a blow-lamp and fill the grooves (6) with sealing compound. While the compound is still hot place the top half of box in position and bolt up.

(*j*) Remove filling plugs (4) and fill glands (10) with sealing compound.

(*k*) *Fill box with insulating compound* (11).—Remove manhole cover (3). Warm outside of box with blow-lamp and fill the box with insulating compound level with the top of the manhole. As contraction proceeds the box must be topped up from time to time. This operation takes several hours to do well (*see* para. 6).

(*l*) When the contraction of the insulating compound is complete fill the groove (6) in manhole with sealing compound, replace manhole cover, screw down and fill the well (7) above the cover with sealing compound.

(*m*) Top up glands (10) with sealing compound, replace filling plugs (4) and fill the well above these plugs with sealing compound.

(*n*) *Paint joint box.*—On completion of the joint give the box and the cable for several feet on each side of the box a couple of coats of bitumastic paint.

8. **Branch connections.**—" T " joints should be avoided as far as possible by leading the cables in and out of a building.

In H.V. work it is generally possible to adhere to this rule, but for the service connections in L.V. and M.V. work, " T " joints will have to be permitted on grounds of expediency.

" T " boxes of the type described above and illustrated in Pl. **56**, Figs. 1 and 2, can be obtained, but the type shown in Fig. 3 on this plate is more commonly used up to 660 volts. It is relatively smaller and cheaper and is also very suitable for handling by semi-skilled jointers. The joints are taped, and therefore the conductors may be closer together, which permits a smaller box to be used. No plumbing is required and no soldering, except of the conductor joints. Bonding of both armouring and lead is through the box by mechanical clamps and lead strip packing.

A " T " conductor joint can be made by opening out of the strands of the branch conductor and lapping the main conductor for two complete turns, about one-half the strands going around clockwise and the other half counter-clockwise, but it is preferable to use special claw connectors, if these can be obtained.

The main conductor should not be cut.—In fact, L.V. and M.V. branch connections are frequently made with the cable alive, in order to avoid interrupting the supply to existing consumers. In these circumstances, the terminating box on the consumer's premises must be fitted before the branch connection is made.

There is obviously an element of risk in handling a *live* cable, and the work should only be entrusted to thoroughly skilled and experienced jointers. For service purposes under peace conditions it should not be necessary to incur any risk in the matter, and the work should therefore be done when the cable is *dead*.

The overall dimensions of a straight-through box of the type under consideration, suitable for 3-core cables from 0·12 to 0·2 sq. in. (4-core 0·1 to 0·12), are 19″ × 6″ × 5½″, and the weight of compound required, insulating 6 lb., sealing 1½ lb.

The overall dimensions of a " T " box suitable for 3-core main cables from 0·12 to 0·2 sq. in. (4-core 0·1 to 0·12), and 3-core branch from 0·007 to 0·04 sq. in. (4-core 0·007 to 0·0225), are 19″ × 11″ × 5½″, and the weight of compound required, insulating 8 lb., sealing 2 lb.

9. **Terminating single-core cables** (*see* Pl. 55, Fig. 1).—No special precautions need be observed when terminating *rubber-insulated cables* but for good neat work the conductor should be sweated into a terminal lug and lapped with guttaroid tape (*Tape, guttaroid, ½-in.*). India-rubber tape and solution may be used if guttaroid tape is not available. Primed tape is hygroscopic and should not be used.

The cable end should be prepared as when jointing, and the tape lapping should be carried well on to the terminal lug.

If guttaroid tape is used, it should be worked by the thumb and fingers whilst being applied in order to exclude air bubbles, and should on no account be stretched at all tight. Three or four layers of cotton tape should then be lapped over it, and the whole immersed in compound heated to 280° F. for a few minutes. After cooling, the cotton tape is stripped off, and the guttaroid shaved down smooth.

The termination of *paper-insulated cables* is best done in an *end-sealing* box. These boxes are not articles of store, but should be specially demanded or provided under local arrangements.

If no *end-sealing* box is available, the termination may be done by jointing on a short length of rubber-insulated lead-covered cable of the same-sized conductor, but such a joint must never be drawn into a pipe nor buried so that inspection is impossible. The ends of the cables are prepared, and the joint is made exactly as has been described above, the only difference being that primed tape is used for insulating, as impregnated cotton tape would injure the rubber.

The other end of the rubber cable should be finished off with the guttaroid tape as described above.

Armoured cables will be terminated in a similar manner to unarmoured cables. The ends of the armouring wires or tape will be cleaned and clamped below the conductor tail joint to the lead sheath, which must then be efficiently earthed. With tape-armoured cables the armour clamp will be fixed at the end of the armouring, and a short length of galvanized iron wire will be connected to it, and then taken a few times round the lead sheath and soldered.

10. **Terminating multicore cables.**—The end sealing boxes for multicore cables are generally of cast-iron, designed in most cases for mounting vertically. Pl. **57** illustrates indoor and Pl. **58** outdoor types. The boxes must be provided with suitable armour clamps when required, and with means for bonding the box, armour and lead sheath together. Where the cable enters the box, a wiped joint between the lead sheath and a brass gland bolted to the box, makes the best seal and bond. The armouring is laid over the wipe and clamped to the barrel of the gland by an independent armour grip. The wiped joint can be obviated, however, by using a lead cone gland (Pl. **58**), which consists of a split lead bush forced into position by a separate malleable iron clamp. The armour is secured independently above the cone clamp as in the case of the wiped joint. Pl. **57** shows a third, much simpler and neater, method in which it is not necessary to open out the armouring (a troublesome operation with tape armour). The lead sheath is bonded to the box by sweating on a copper strip as in the joint boxes previously described. In the illustration, compounded canvas packing is shown, but to avoid using a separate armour bond, lead strip should be used. No space is available to discuss these designs further, but they are all quite satisfactory.

It is important to see that the paper insulation is well covered with compound and that the boxes are not filled

PLATE 57.

INDOOR VERTICAL WALL TYPE TERMINATING BOXES.

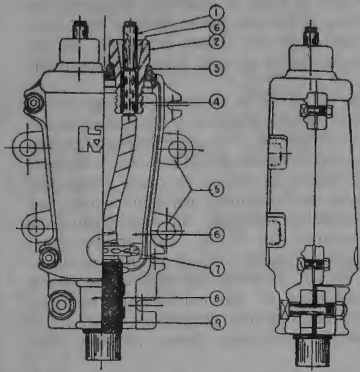

Fig. 1.—Low Voltage.

1. V.I.R. Tail.
2. Porcelain Insulator.
3. Cast-Iron Top.
4. Tinned Brass Connector.
5. Lugs for wall fixing.
6. Filled with compound.
7. Tinned copper earthing strip.
8. Cast-Iron Cable Grip.
9. Compounded Canvas wrapping.

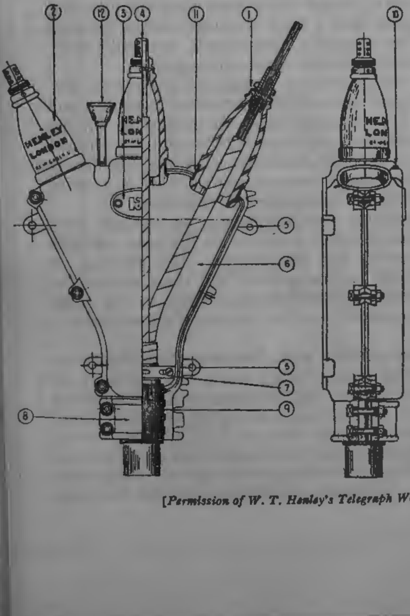

Fig. 2.—High Voltage.

1. Brass Cap.
2. Porcelain Insulator.
3. Filling and inspection cover.
4. Tinned Brass Connector.
5. Lugs for wall fixing.
6. Filled with Compound.
7. Tinned copper earthing strip.
8. Cast-Iron Cable Grip.
9. Compounded canvas wrapping.
10. Filling Plug.
11. Rubber Ring.
12. Filling Funnel.

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quite full, as they are subjected, as a rule (particularly outdoor type), to greater changes of temperature than underground joints, and room must be left for expansion. For the same reason, a compound which is solid at ordinary temperatures must always be used, since if the compound melts it may flow down into the cable and leave the paper exposed. In the tropics it is advisable to use a special high melting-point compound.

The L.V. box shown in Pl. **57** is designed for connecting on V.I.R. or Empire tape tails, and the H.V. box is arranged for bare connections, with ample clearances between wires, but obviously insulated tails can be provided for if desired. To obviate joints in terminating boxes, in cases where the connections to switchgear or machinery are quite short, the cable cores may be continued through, the core insulation being removed and replaced by V.I.R. or Empire tape. When V.I.R. tape is used, a length of half an inch or so of bare conductor should be left between the end of the paper insulation and the beginning of the rubber-tape serving. This short length of conductor should preferably be soldered solid to prevent moisture creeping down between the strands.

The modifications in design consequent upon the necessity for weather protection and a large creepage surface between conductors which are generally uninsulated, naturally make outdoor type terminating boxes relatively expensive.

One type has the outgoing insulators separately surrounded by metal belts to shield the insulators from rain and deposits of dust, &c. Another type, illustrated in Pl. **58**, which is now considered to be more reliable and less subject to flashing over, has exposed insulators with large petticoats which rely upon their long creepage surface and to rain to wash away any salt or dirt which may be deposited.

The most satisfactory way of jointing up outdoor type boxes is with the box fixed in position on the pole, suitable staging being provided for the jointer. The method of carrying out the work on the ground and then raising the cable and box is liable to cause serious injury to the cable (especially if tape armoured) and to fracture the insulators.

11. **Distribution pillars and disconnecting boxes.**—For the disconnecting arrangements which are necessary at feeding points, road corners, &c., underground disconnecting boxes are frequently used in residential areas, and it is sometimes difficult to avoid using them on L.V. systems, but it is in all cases preferable to make the connections above ground either within a convenient building or in a special overground distribution pillar. The main connections between the cable

INVERTED OUTDOOR TYPE TERMINATING BOX.
3,300 TO 20,000 VOLTS. (See Section 43)

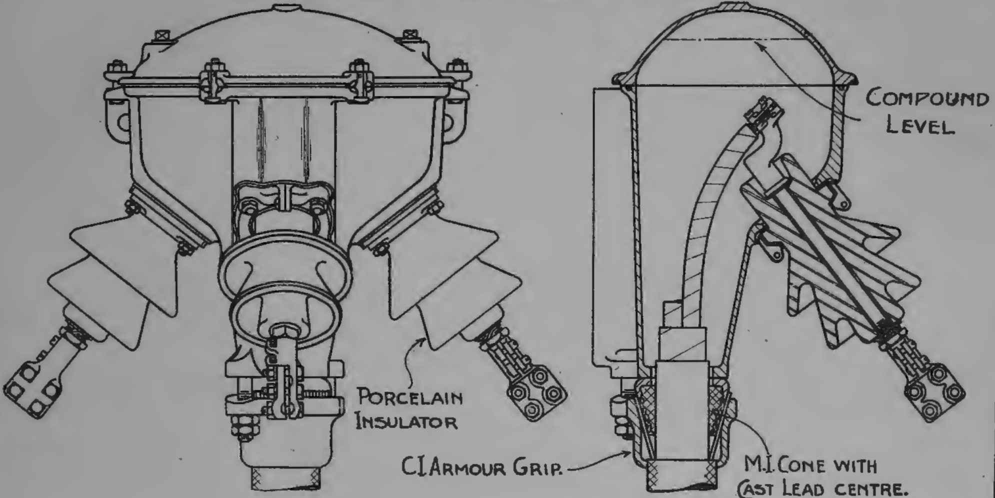

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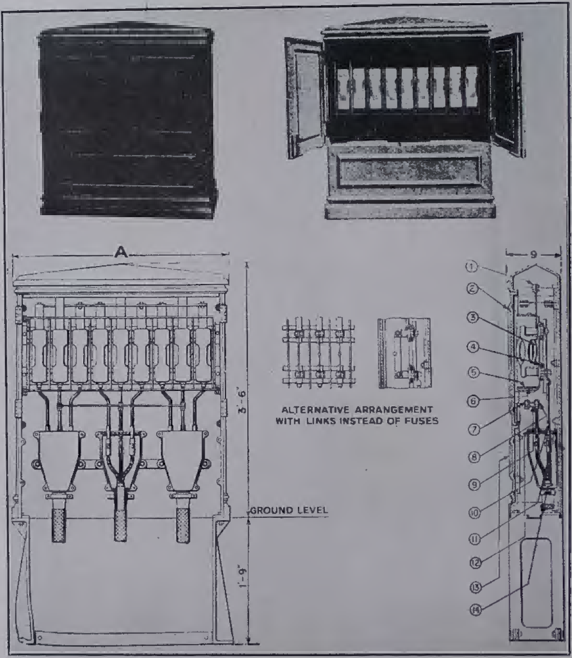
PLATE 58.

[To face p. 222.

DISTRIBUTION PILLAR.



1. Bus-Bars.
2. Doors.
3. Porcelain Handle Fuses.
4. Insulated Carrier Bars.
5. Labels
6. Arc Shields.
7. Neutral Bar.
8. Neutral Link.
9. Insulating Support.
10. Bakelised Paper Sleeves.
11. Compound filling to Here.
12. Insulating Lid.
13. Removable Cover.
14. Box Split on Centre Line.

Minimum of Space occupied on Pavement. Can be fixed against Wall or Hedge, depth being only 9 inches. Overcomes all difficulties inseparable from Underground Link Boxes in Manholes.

[*Permission of W. T. Glover & Co., Ltd.*

ends may be made either by links or fuses, but fuses must not be inserted in the neutral conductor.

The principal cable manufacturers have standard designs of these pillars to suit all purposes.

Pl. **59** shows a simple type for a 3-phase 4-wire system, the width " A " being about 3 feet for the 3-way pillar illustrated.

An alternative arrangement of the fuses is in three horizontal rows, one above the other, fuses of the same polarity being in the same row. This is a somewhat better arrangement electrically, and it results in a narrower but higher and somewhat deeper carcase. As these pillars may sometimes have to be fitted into awkward corners, this alternative arrangement should be borne in mind. In this connection it may be mentioned that in the Henley design, a special type of end sealing box is used which permits the cores to be brought out at appropriate distances apart vertically one above the other.

44. *Records and testing.*

1. Electric cables are very costly, and are liable to deteriorate rapidly if not properly stored, handled, and looked after when laid. Proper care of them is, therefore, most important.

It is not proposed to go into detail concerning the origin of faults, though their localization will be briefly dealt with in the next section ; but it may well be pointed out here that at least 30 per cent. of the faults which develop are traceable to lack of care during laying, although they may not actually appear until some months afterwards.

All cables suffer greatly from ill-treatment, and paper and bitumen cables especially cannot be handled too carefully. No cable should be bent sharply or unnecessarily, and the necessity for, and the methods of, sealing the ends when not in use have already been explained.

Furthermore, it must be borne in mind that it is impossible to tell by visual inspection alone whether a cable is in good condition or not. This can only be ascertained by electrical tests, and so the periodic testing of cables is of paramount importance. To ensure that this periodical testing is properly carried out, a careful record of the condition and distribution of all cables should be kept in a Cable Record Book.

The necessity for preserving a complete record of the exact position of all cables when laid and the positions of joints and boxes has already been mentioned in Sec. **41**, and to this may well be added such details as the nature of the soil, the weather conditions when laying, any departure from normal methods, likelihood of disturbance, &c. Thus a complete electrical history of every length of cable will be available for reference, and in the event of a fault occurring its localization will be greatly facilitated.

After laying and, in the case of the *direct-laying* and *solid* systems, before filling in, rough tests of the C.R. and I.R. of each length of cable should be made and recorded. Final tests should be made when all jointing has been done and the laying operations are complete; these final tests should be recorded in the Cable Record Book.

Very accurate tests of all cables are made before supply, so the tests mentioned above and all periodic tests can be carried out by means of the Bridge-Megger, the Megger, or similar apparatus for the insulation test, and the Bridge-Megger or Coils, resistance, 10,000 O, Mark V, for the conductivity test.

It must be noted that the figures for minimum insulation resistance given in Appendix VI apply only at a temperature of 60° F. Both rubber and paper have large negative temperature coefficients and the insulation resistance therefore falls rapidly with rise of temperature.

The insulation resistance of a paper cable at 80° F. is only one-fifth the value at 60° F.

If any degree of accuracy is to be obtained in the insulation tests, great care must be taken in the preparation of the ends of the cables, in order to reduce the possibilities of leakage to a minimum.

Cleanliness and dryness, as in the art of jointing, are all-important features, and a band of paraffin wax should be put in the leakage path as an additional safeguard. The ends of the wire joining the conductor to the Megger should be similarly treated. Unless these precautions are taken the test may be one of the end of the cable only and not a reliable indication of the state of the cable throughout.

It must be remembered that on no account should the megger be used for testing gutta-percha cables. A battery of from 30 to 50 cells should be employed.

In performing conductivity tests, allowance must be made for the resistance of the connecting wires, and the joints between them and the conductors should be very carefully made.

Of almost equal importance with the tests before and immediately after laying are the subsequent routine tests of the system or network, and the E.C. regulation bearing on the matter is as follows :—

> 4. The insulation of every electric circuit whether connected with earth in accordance with these regulations or not . . . shall be so maintained that the leakage current shall not exceed one-thousandth part of the maximum supply current; and suitable means shall be

provided for the indication and localization of leakage. Every leakage shall be remedied without delay. Every circuit shall be periodically tested for insulation.

It must be pointed out, however, that, in the case of paper cables, it is the *dielectric strength* which is the true criterion of the quality of the insulation. To comply with the British Standard Specification, cables when first laid and jointed should withstand a voltage of 1·75 times the working voltage applied for 15 mins. (for exact figures the specification must be referred to). The Electricity Commissioners Regulations also require voltage tests of electric mains to be made before they are taken into use, the figures at present laid down being (*a*) For L.V. and M.V. cables: the working voltage; (*b*) H.V. cables: 1·5 times the working voltage; (*c*) E.H.V. cables: twice the working voltage applied for half an hour in all cases.

It is not usual, however, to subject cables to excess voltages for periodical testing.

2. On **D.C. and A.C. single-phase 2-wire systems,** a common and useful method of obtaining a rough indication of the state of the insulation of the system may be obtained by connecting two exactly similar lamps across the bus-bars with the centre point earthed (*see* Fig. 41).

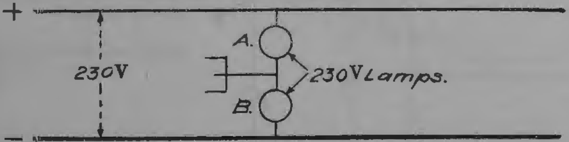


Fig. 41.

The lamps should be for the bus-bar voltage, so that, if the insulation of the system is perfect, both will glow dimly; if, however, the insulation on, say, the negative main begins to fail, lamp A will glow more brightly than lamp B, whilst a *dead earth* on the negative will cause lamp A to give its full light, and lamp B will not glow at all.

It will be obvious that this method fails if both mains develop a fault simultaneously.

3. On **A.C. 3-phase networks** an *indication* of the condition of the cable can be obtained either by means of lamps or by means of a voltmeter connected as shown in Fig. 42 for a 3-phase system.

The voltmeter switch should be left normally in position 4, where it is connected to an artificial neutral point, and the needle should be at zero. If a fault develops, a current will flow through the voltmeter, and the faulty main can be discovered by switching to 1, 2, and 3 in succession. A faulty main will, of course, give a reading with the voltmeter connected to either of the other two, provided the other two mains are in good condition. If two mains are faulty, then the largest deflection will be obtained with the voltmeter connected to the sound one. If the generators or transformers are star-connected with the neutral point earthed, this latter earth connection must be broken before taking readings on the individual mains. (*See also* Sec. **22**, and Pl. **44.**) ***Ensure that the earth connection is remade when the test is completed.***

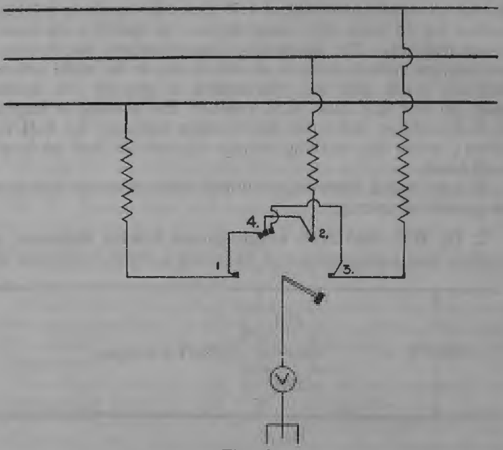


Fig. 42.

45. *Localization of faults.*

1. The faults which may occur on cable systems can be classified under the following heads :—

i. Disconnections.
ii. Short-circuits, between two adjacent cables or between two cores of a multiple cable.
iii. Contacts, between conductor and earth.

Any combination of these may be met with. Disconnection unaccompanied by an earth fault are rare, and short-circuits are also comparatively infrequent, so that the majority of trouble to be anticipated will be of the nature of leakages to earth.

Systematic testing, as described in Sec. **44**, will in a great number of cases give an indication of the development of a fault before it becomes bad enough to cause a dislocation in the supply services, and, when a fault does occur, an intimate knowledge of the system, coupled with complete records, will often lead to its location without further trouble.

Where there is no indication, however, the faulty section must first of all be discovered by isolating sections in turn and noting whether the fault remains on or not. Then one or more of the following tests must be applied. Many elaborate tests for the localization of faults have been devised, and those that are given are selected as types.

2. **Tests for disconnection.**—If accompanied by an earth fault, then the simplest method is to locate the *earth*, as described below. If, however, there is no earth, then a *capacitance test* can be resorted to.

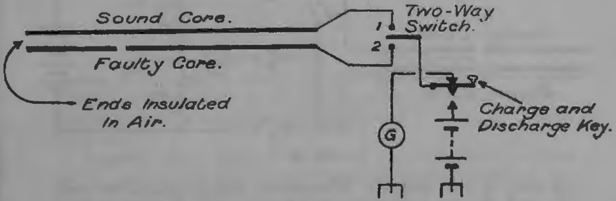


Fig. 43.

i. The simplest test consists of *comparing the capacitance* of the faulty cable or core with the capacitance of a sound core of the same cable or of a similar cable laid alongside.

A battery (say of 10 cells), ballistic galvanometer, and charge and discharge key are connected up as in Fig. 43.

With the switch on contact 1 the key is depressed for a definite period of time, say 10 seconds. It is then released, and the throw on the galvanometer is noted.

The operation is repeated with the switch on contact 2.

Suppose that the galvanometer readings are d_1 and d_2, l is the length of the sound core or cable, and x the distance of the fault from the end under test,

$$\text{then } l : x = d_1 : d_2$$

$$\text{and } x = \frac{d_2}{d_1} \times l.$$

The result may be checked by repeating the test at the other end.

In the event of there being disconnections on all the cores of a multiple cable, tests must be made at both ends of one of the cores. Then, if the galvanometer readings are d_1 and d_2 and x is the distance of the fault from the first end,

$$x = \frac{d_1}{d_1 + d_2} \times l.$$

Before making this test it is necessary to ascertain by a megger test whether the insulation resistance is up to its normal, for, if the insulation of the cable has suffered, the test will not be reliable. Similarly, it is important that all the connecting leads and apparatus should be thoroughly well insulated and dry.

ii. Fig. 44 shows the *zero method*, invented by Lord Kelvin, of performing the capacitance test, the principle being similar to that of the ordinary Wheatstone Bridge resistance test. R_1 and R_2 are adjustable resistances, and G is a ballistic galvanometer. The battery and all portions of the circuit should be thoroughly well insulated.

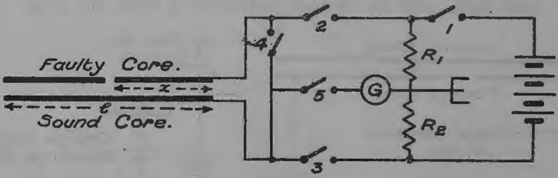


Fig. 44.

The method of making the test is as follows :—

Close key 1. Then the potentials V_1 and V_2 across the resistances will be such that $V_1 : V_2 = R_1 : R_2$.

Close keys 2 and 3 simultaneously for a fixed period of, say, 10 seconds. Then the faulty and sound cores will be charged to potentials V_1 and V_2 respectively, and, if Q_1 and Q_2 are the charges given, then

$$Q_1 : Q_2 = V_1 \times x : V_2 \times l.$$

Release keys 2 and 3, and close key 4 for 10 seconds to allow the charges to mix. If $Q_1 = Q_2$, there will be no deflection on the galvanometer when key 5 is closed, and R_1 and R_2 must be adjusted until the desired result is obtained.

$$\text{Then } V_1 \times x = V_2 \times l.$$
$$\text{But } V_1 : V_2 = R_1 : R_2$$
$$\therefore x = \frac{R_2}{R} \times l.$$

3. Tests for short-circuits.—In these tests it is highly important that the resistances of the connecting leads be taken into account, and that the connections be thoroughly well made.

i. Fig. 45 gives the connections necessary for a simple *fall-of-potential test.* R is a known resistance of approximately the same value as half the cable under test, and the far end of one of the cores is connected to earth. V is a low-reading voltmeter or galvanometer, the readings of which are proportional to the currents through it, and it must be of high resistance.

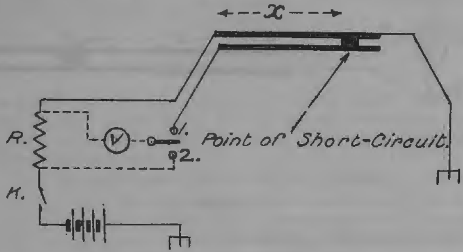


Fig. 45.

Suppose that, when K is closed, the voltmeter readings are V_1 and V_2, with two-way switch at 1 and 2 respectively then resistance of x : R $= V_1 : V_2$, and the length x can easily be computed, since the size of the conductor is known, and consequently the resistance per unit length.

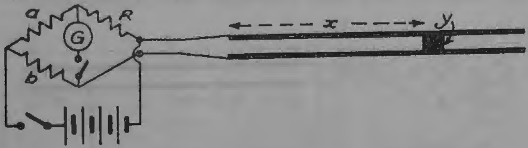


Fig. 46.

To check the result, readings may be taken at the other end of the cable.

If the short-circuited cores are also making earth, the method is unaltered.

ii. Figs. 46 and 47 show how a *loop test* for a short-circuit may be made, whereby the actual resistance of the contact (y) is eliminated.

First let the far ends of the two cores be insulated in air, and connect up as in Fig. 46.

Then when a balance is obtained,

$$\frac{R}{2x + y} = \frac{a}{b}.$$

Then join the far ends of one of the cores to earth, and connect up as in Fig. 47.

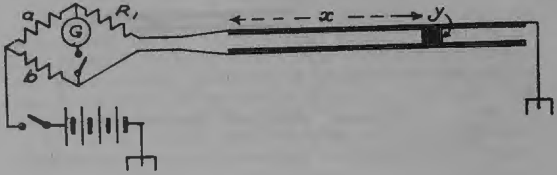


Fig. 47.

When a balance is obtained,

$$\frac{R_1 + x}{x + y} = \frac{a}{b}.$$

From these two results the value of x and, consequently, the distance of the fault can be found.

It will be noticed that, if the arms of the bridge are equal in both cases, then $x = \frac{1}{2}(R - R_1)$.

4. **Tests for earth faults.**—In attempting to locate an earth fault on a cable, it must be borne in mind that the earth contact itself will possess ohmic resistance and that it may also contain an E.M.F.

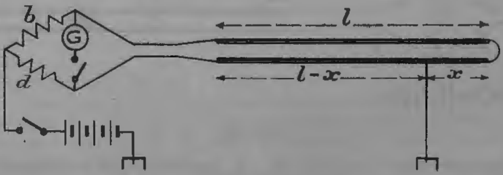


Fig. 48.

i. *Loop tests* are very commonly employed for this purpose, and possess the merit of being entirely independent of the fault resistance. They are rather more accurate than the fall-of-potential method and more generally applicable than the search-coil method. If a sound core or cable on the same route does not exist, then an interruption cable must be run along the surface to complete. The connections for Murray's loop test are given in Fig. 48. For accuracy a battery of low resistance and a sensitive dead-beat galvanometer are required, or a "Bridge Meg Testing Set" may be used.

The sound and faulty cores or cables are looped at the far end, and the resistance d adjusted until a balance is obtained.

$$\text{Then} \qquad \frac{b}{d} = \frac{l + x}{l - x}.$$

$$\text{Whence} \qquad x = \frac{b - d}{b + d} \times l.$$

Allowance will, of course, have to be made if the sound and faulty cables have conductors of different sizes, and *Kempe's Electrical Testing* gives the following as the best conditions for the test :—

(*a*) The resistance b should be as high as is necessary to give the required range of adjustment in d; if b and d would in this case require to be excessive compared with the resistance of the loop, d must be adjustable to a fraction of a unit.

(*b*) The resistance of the galvanometer should not be greater than 5 times the resistance of the looped cables.

(*c*) The battery power should be sufficient to give a deflection if d is a unit or a fraction of a unit out of adjustment.

With the connections as shown in Fig. 48, it is of course wrong to balance to a false zero, since the fault E.M.F. is in the battery circuit only. If a deflection is obtained by pressing the galvanometer key only, it means that there is a leakage to earth from the instruments, and this leakage must be cleared before proceeding with the test.

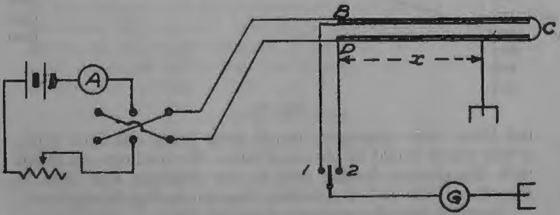


Fig. 49.

ii. *Fall-of-potential tests* are simple, though scarcely as accurate as loop tests. One method is indicated in Fig. 49, and it will be noted that a sound cable or core is again needed to form a loop.

G is in this case a central-zero milli-voltmeter, and a reversing switch is introduced so that the mean of two pairs of readings may be taken.

Suppose that the first pair of readings are V_1 (Right) and V_2 (Left), respectively, that when the direction of current is changed by means of the reversing switch the readings are v_1 (left) and v_2 (right), and that the total length of the loop is l.

$$\text{Then} \quad \frac{x}{l-x} = \frac{V_2 + v_2}{V_1 + v_1}$$

$$\text{or} \quad x = \frac{V_2 + v_2}{V_1 + v_1 + V_2 + v_2} \times l.$$

If there is no E.M.F. in the earth circuit, then V_2 will be equal to v_2 and V_1 to v_1. The reversing switch in this case would not have been necessary, but, if such a *sea cell* does exist, a false result would be obtained unless the readings are taken with the current flowing first in one direction and then in the other. The fall-of-potential diagram in Fig. 50 explains.

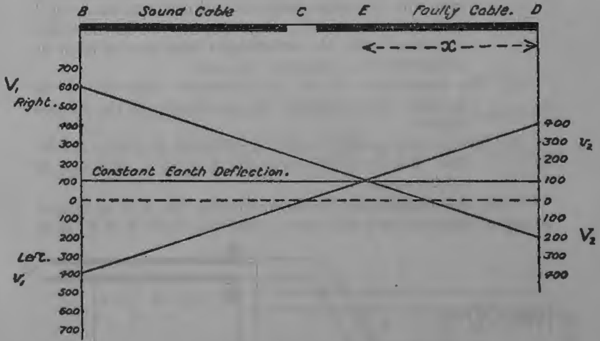


Fig. 50.

Suppose that the readings obtained are :—

	Stud 1.	Stud 2.
Current flowing from B to D.	600 Right.	200 Left.
,, ,, ,, D to B.	400 Left.	400 Right.

It will be obvious that there is a constant earth deflection of 100, and that E, the position of the earth fault, is such that DE is $\frac{400 + 200}{600 + 400 + 400 + 200}$ or $\frac{3}{8}$ of DB.

iii. *Search-coil*, or *induction*, *tests* have the merit of being very simple and rapid.

The principle of the test is to pass an interrupted or alternating current through the cable and fault (*see* Fig. 51), and to walk along the surface with a search coil, the ends of which are attached to a telephone receiver. A search coil of triangular shape with 3-foot sides and wound with about 200 turns of about No. 28 S.W.G. insulated wire is most convenient. Until the fault is reached a buzz (intermittent current) or a hum (A.C.) is heard in the receiver, but this is not heard when the fault has been passed.

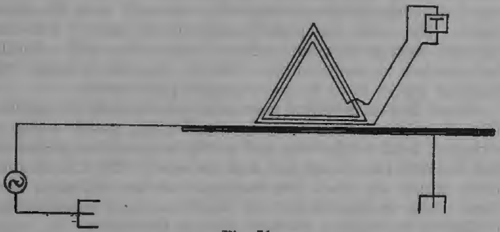


Fig. 51.

This test, however, is by no means wholly reliable with lead-covered or armoured cable or with cables in metal conduits or pipes, since the interrupted or alternating current may continue in the sheathing beyond the fault, or may *return* along the sheathing for a certain distance and neutralize to a certain extent the inductive effect of the current in the core. Moreover, an accurate knowledge of the underground conditions in the neighbourhood of the fault is necessary, since a line of water pipes or similar metallic line is very likely to mislead the operator.

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"Electric Mains and Distributing Systems." Dick and Fernie. 18*s*.

The Art and Craft of Cable Jointing. C. G. Watson. 6*s*.

British Standard Specifications :—

7. Insulated Annealed Copper Conductors. 2*s*.

Government Department Electrical Specifications :—

1. Electric Cables, J. K. and L. Classes.
12. Electric Cables, K. P. and L. P. Classes.
9. Electric Cables, N. Classes.

Inter-departmental Specification No. 5 (1930), for the supply and installation of paper insulated underground cables and apparatus for low voltages.

CHAPTER VI.

OVERHEAD LINE CONSTRUCTION.

46. *General considerations.*

1. The **respective merits** of **overhead lines** and **underground cables** have already been discussed, mainly from the point of view of their suitability for high-voltage lines, in Chap. III, where it was pointed out that the advantages of overhead lines considerably outweigh their disadvantages. The same arguments apply in the case of low- and medium-voltage distribution lines, but as these will naturally be situated in more or less thickly populated areas, the æsthetic aspect must be given greater prominence.

Great Britain is behind most other countries in the application of overhead lines to rural distribution, partly owing to stringent legal regulations, and partly to parochial prejudice; but the 1926 Electricity Act, and the new (1928) E.C. Regulations, which are much less onerous than the old ones, have done much to remove the old objections, and extensive use is likely to be made of overhead lines in the future.

For military purposes, an important advantage of overhead lines is that the conductors are visible. This is very desirable where personnel are frequently changed.

Under peace-time conditions all W.D. installations should comply strictly with the regulations of the Electricity Commissioners and the Postmaster-General, but on active service rigid compliance is unnecessary and frequently impossible.

Signal Training, Part IV, gives useful information regarding overhead line construction.

47. *Conductors.*

1. The factors affecting the selection of the **materials for conductors** are many, chief among them being conductivity, specific gravity, tensile strength, area exposed to wind pressure, and price, but such things as linear expansion with rise of temperature, ease of erection and jointing, and chemical inertness against atmospheric effects must also receive consideration.

2. Ordinarily the choice lies between hard-drawn **copper** and **aluminium**, and much has been written on the relative advantages of these two materials; but copper is on the whole preferable. Aluminium has the advantage in so far as weight is concerned, but its tensile strength is much less than that of copper, and its greater area (for equal conductivity) exposes

it to a greater ice-load and a greater wind-pressure. Consequently, a greater sag is necessitated, and the supports, for equal spans, have to be taller than is the case for copper wires; this may counterbalance the advantage due to the saving in weight. In sea air aluminium is more durable than copper, but it should not be installed in the vicinity of chemical works, nor should it be left lying about in marshy ground or in stables, where ammonia may be present.

The main objection to aluminium is that it is *difficult to solder*, owing to its property of rapid oxidation. Consequently, joints have to be made either by welding or by means of clamps (*see* Sec. **54**). Clamps, however, do not get rid of the oxidation trouble, so the use of aluminium is not recommended for L.V. distribution systems, since every joint and branch may introduce a comparatively high resistance, and be the cause of an excessive voltage drop.

From the point of view of erection cost alone, it will be found that aluminium is preferable to copper if its price per lb. is much less than twice that of copper.

It should also be noted that copper has a considerably higher scrap value than aluminium.

If copper is used for a H.V. line it must be hard-drawn, but copper of medium hardness (tensile strength 43,000 to 51,500 lbs. per square inch) is permissible for local overhead distributing systems, where spans are normally rather less than those of H.V. transmission lines. It is better, however, for Service purposes, to use only hard-drawn wires, and so avoid the possibility of medium hard-drawn wires being erected by mistake when the use of the former is imperative. Soft annealed copper should not be used. Aluminium wires should be hard-drawn.

3. It is to be noted that the chief mechanical strength of copper and aluminium hard-drawn wires lies in their outer skin, which accounts for two figures being given in each case for tensile strength in Table F, the lower figure being for wires of larger section (about 1 square inch) and the higher figure for wires of small section (about 0·012 square inch): B.S. Specification No. 125 for copper and No. 215 for aluminium should be referred to for precise figures. In stranded cables the tensile strength is determined by the size of the strands, and for this reason it is preferable to use them. It is recommended that *solid copper wires should not be used for larger sections than* 0·0289 *square inch* (*approximately No.* 6 *S.W.G.*). It is also recommended that *solid aluminium wires should never be employed* for the reasons that manufacturers find it difficult to ensure sufficient homogeneity in any but the smaller wires.

Another point in favour of stranded cables is that they are much easier to handle and less liable to unsightly kinks than solid wires, though subject to *caging* if due care is not exercised.

The factor of ***skin strength*** must be borne in mind when *wiring* (*see* Sec. **53**), and on no account should the cables be dragged over hard stony ground. Even greater care is necessary with aluminium cables than is the case with copper.

A stranded cable will generally break under a load slightly smaller than the combined breaking loads of the individual wires, but the tensile strength should not be less than 90 per cent. of the combined strengths of the single wires; the resistance of a stranded cable is approximately 2 per cent. higher than the resistance of a solid wire of equal cross-sectional area (*see* Sec. **36**).

4. For exceptionally long spans where tensile strength is of more importance than electrical conductivity, it may be necessary to use **iron, steel, bronze, or copper-clad steel cables,** or **stranded cables (aluminium or copper) with a central core of steel.**

The specific conductivity of iron and steel is less than one-sixth that of copper, and, further, owing to its high permeability the apparent increase of resistance due to skin effect is very marked, and its internal reactance is considerably greater than that of copper. For large currents, therefore, its use is confined to special cases where great strength is required, such as in specially long spans. But it will frequently be found (particularly in H.V. work) that the size of a copper conductor, when calculated from purely electrical considerations, is too small from a mechanical point of view. The possibility of using galvanized iron or steel should then be carefully considered. It has been found that, provided the wire is stranded and the current per strand does not exceed 1A, the heating losses and voltage drop in the conductor will not very greatly exceed those to be expected with a copper conductor of the same ohmic resistance. However, the life of iron and steel wire is rather short, especially in manufacturing areas, and its scrap value is negligible.

Copper-clad steel wire is made by welding a coating of copper on to a steel wire by means of a special copper-iron alloy, and the finished wire has a conductivity of from 30 to 40 per cent. of a copper wire of the same diameter.

A central steel core for stranded cables is chiefly of use with aluminium cables, the current-carrying capacity of the steel being neglected in the calculation of the conductivity; the strength of hard-drawn copper is so great that little is gained by the addition of a steel core.

5. Table **F** gives the main properties of hard-drawn copper, aluminium, and copper-clad steel.

TABLE **F**.—*Properties of conductor materials for overhead lines.*

Property.	Copper, hard-drawn, solid or stranded.	Aluminium, hard-drawn, stranded.	Copper-clad steel, 40 per cent.	Copper-clad steel, 30 per cent.
Breaking stress, lb. per sq. inch..	50,000 to 65,000	22,000 to 30,000	60,000 to 100,000	60,000 to 100,000
Elastic limit, lb. per sq. inch	30,000 to 35,000	14,000 to 17,000	50,000	50,000
Modulus of coefficient of elasticity (Young's modulus)	18×10^6	$9{\cdot}6 \times 10^6$	20×10^6	20×10^6
Electrical conductivity (Silver=100)	97·5	58·5	38	28·5
Resistance of conductor 1,000 yards long, 1 sq. inch cross section, 60° F., ohms	0·02443	0·0407	0·06254	0·08331
Weight per 1,000 yards, 1 sq. inch cross-section, lbs.	11,700	3,520	10,730	10,730
Coefficient of linear expansion per °F. ..	$9{\cdot}222 \times 10^{-6}$	$12{\cdot}6 \times 10^{-6}$	$6{\cdot}7 \times 10^{-6}$	$6{\cdot}7 \times 10^{-6}$
Ratio of conductivities for equal area	1·0	0·6	0·4	0·3
Ratio of areas for equal resistance	1·0	1·66	2·56	3·41
Ratio of weights for equal area	1·0	0·33	0·94	0·94
Ratio of weights for equal resistance	1·0	0·55	2·62	3·41

48. *Sag and stress calculations.*

1. The size of conductors having been decided upon from electrical considerations, calculations are necessary to determine the sags and tensions to be allowed for erection purposes. The first step in these calculations is to find the **minimum sag under worst loading conditions.**

The hypothetical worst loading condition for Great Britain as prescribed in the latest (1928) Electricity Commissioners' Regulations for Overhead Lines is as follows :—

H.V. Lines (above 650 volts D.C. and 325 volts A.C.). Temperature 22° F. ; ice loading ⅜-inch radial thickness ; wind pressure 8 lb. per square foot horizontally on the whole of the projected area of the ice-covered conductor ; factor of safety 2.

L.V. and M.V. Lines.—In order to permit a lower real factor of safety, the ice loading is taken as $\frac{3}{16}$-inch. All other conditions remain the same.

Let d_o = diameter of wire in inches,
t = radial thickness of ice covering in inches,
d = diameter of ice-covered wire in inches,
w_o = weight of wire alone in lb. per foot run,
w = weight of ice-covered wire in lb. per foot run,
p = wind pressure (assumed horizontal) in lb. per foot run,
W = total resultant loading of wire in lb. per foot run.

Then $d = d_o + 2t$,
$w = w_o + 1{\cdot}25t(d_o + t)$, the weight of ice being 57·5 lb. per cub. ft.,
and $W = \sqrt{w^2 + p^2}$.

Next it can be assumed that the wire hangs in a parabolic curve, which is sufficiently accurate for all practical purposes.

$$\text{Then } D_{22} = \frac{L^2W}{8T_{22}},$$

where D_{22} = sag in feet at 22° F.,
L = length of span in feet,
T_{22} = safe permissible load in lb., *i.e.*, $\frac{\text{breaking load}}{\text{factor of safety}}$,
and W = resultant loading of wire in lb. per foot run as found above.

Consider a 0·02926 square inch H.D. copper conductor on a H.V. line with a span length of 200 feet. $d_o = 0{\cdot}193$, $w_o = 0{\cdot}1127$, $T_{22} = 874$ (*see* Table A), $d = d_o + 2t = 0{\cdot}193 + 2 \times 0{\cdot}375 = 0{\cdot}943$ in., $w = w_o + 1{\cdot}25t(d_o + t) = 0{\cdot}1127 + 1{\cdot}25 \times 0{\cdot}375(0{\cdot}193 + 0{\cdot}375) = 0{\cdot}379$ lb.

$$p = \frac{8d}{12} = \frac{8 \times 0{\cdot}943}{12} = 0{\cdot}629 \text{ lb.}$$

$$W = \sqrt{w^2 + p^2} = \sqrt{0{\cdot}379^2 + 0{\cdot}629^2} = 0{\cdot}73 \text{ lb.}$$

$$D_{22} = \frac{WL^2}{8T_{22}} = \frac{0{\cdot}73 \times 200^2}{8 \times 874} = 4{\cdot}18 \text{ feet.}$$

2. **Sag and tension for erection purposes.**—The calculations involved are rather complicated, since expansion due to increase of temperature is accompanied by contraction due to elasticity. For a full investigation of the subject reference should be made to one of the text-books given at the end of the chapter.

The following simple treatment will suffice for service purposes:—

Starting from 22° F. with ice loading, as the temperature rises the wire elongates, and the sag increases up to 32°, F., when the reduction in loading due to the melting of the ice results in contraction due to elasticity. As the temperature continues to rise, the sag increases again until at a certain temperature the sag has again the same value that it had originally under the basic loading conditions at 22° F. The temperature at which this occurs is called the *critical temperature*, the conception being of great use in solving sag and stress problems in overhead line conductors. To find the particular temperature we proceed as follows :—

3. **Critical temperature.**—Let D_m, S_m, and T_m denote the sag, stress and tensile load respectively, under the basic loading conditions, and D_c, S_c, and T_c the values at the critical temperature.

$$\text{Then}\quad D_c = D_m = \frac{WL^2}{8T_m} = \frac{w_oL^2}{8T_c}$$

$$\therefore \qquad T_c = \frac{w_o}{W} \times T_m, \text{ and } S_c = \frac{w_o}{W} \times S_m$$

Let θ_c denote the critical temperature, K the coefficient of linear expansion per degree F, $= 9{\cdot}222 \times 10^{-6}$, and $M =$ the modulus of electricity in lbs. per square inch, $= 18 \times 10^6$. Then if $l =$ the length of wire in span,

The *elongation* due to temperature rise $= lK(\theta_c - 22)$, and the *contraction* due to elasticity $= (S_m - S_c)\frac{l}{M}$.

These values are equal; therefore, equating one to the other, we get

$$\theta_c - 22 = \frac{S_m}{KM}\left(1 - \frac{w_o}{W}\right) = \frac{S_m}{166}\left(1 - \frac{w_o}{W}\right).$$

Substituting the known values for 0·02926 square inch conductor we get

$$\theta_c - 22 = \frac{29900}{166}\left(1 - \frac{0{\cdot}1127}{0{\cdot}73}\right) \text{ and } \theta_c = 174° \text{ F.}$$

Note that the critical temperature is independent of the length of the span.

4. **Sag at 22° F. without ice and wind.**—Let D_m, S_m, and T_m refer to loading conditions with ice and wind, and D_o, S_o, and T_o without.

$$\text{Then } D_m = \frac{W_mL^2}{8T_m} \text{ and } D_o = \frac{w_oL^2}{8T_o},$$

$$\therefore \qquad \frac{D_m}{D_o} = \frac{W_mT_o}{w_oT_m} = \frac{W_mS_o}{w_oS_m} \text{ and } S_o = S_m \cdot \frac{D_mw_o}{D_oW_m}.$$

$$\text{Length of wire in span} = l = L + \frac{8D^2}{3L}.$$

The *elastic contraction* due to removal of wind and ice

$$= (S_m - S_o)\frac{l_m}{M} = \frac{S_m l_m}{M}\left(1 - \frac{D_m w_o}{D_o W_m}\right).$$

This is equal to the change of length of wire in span

$$= l_m - l_o = \frac{8}{3L}(D_m^2 - D_o^2).$$

Equating one to the other we get

$$D_m^2 - D_o^2 = \frac{3S_m L^2}{8M}\left(1 - \frac{D_m w_o}{D_o W_m}\right).$$

[No appreciable error is introduced by putting L for l at this stage.]

Substituting values for 0·02926 square inch conductor, we get

$$4{\cdot}18^2 - D_o^2 = \frac{3 \times 29900 \times 200^2}{8 \times 18 \times 10^6}\left(1 - \frac{4{\cdot}18 \times 0{\cdot}1127}{D_o \times 0{\cdot}73}\right).$$

$$D_o^3 + 7{\cdot}4D_o - 16 = 0, \text{ and } D_o = 1{\cdot}61 \text{ feet.}$$

We now have for the unloaded wire in still air

$$D = 1{\cdot}61 \text{ feet when } \theta = 22°,$$
$$\text{and} \quad D = 4{\cdot}18 \text{ feet when } \theta = 178°.$$

If these points are plotted, the straight line drawn through them may be assumed to give the relationship between sag and temperature for the particular span length considered with sufficient accuracy for practical purposes.

Lines are drawn in Pls. **60** and **61** for some of the conductors given in Table A on a span length of 200 feet.

Unfortunately, the calculations for the sag at 22° F. must be repeated for other lengths of span, but, as will be seen above, this is only a few minutes' work.

Knowing the sag at any particular temperature, the tension can easily be obtained from the formula $T = \frac{w_o L^2}{8D}$.

Pulling up the wires to the maximum permissible stress naturally reduces the height of poles to a minimum, but it may not result in the greatest convenience and overall economy, since the greater the stress in the wires, the greater the unbalanced loads to be dealt with at angles and terminals. This should always be borne in mind, particularly with the larger conductors.

When it is intended to work at a lower maximum stress, it is not sufficiently accurate to assume that the sag should be increased proportionately, but the calculation must be based from the beginning upon the value of stress chosen.

5. Maximum vertical sag.—This is required when determining the height of pole necessary to give the conductor the

PLATE 60.

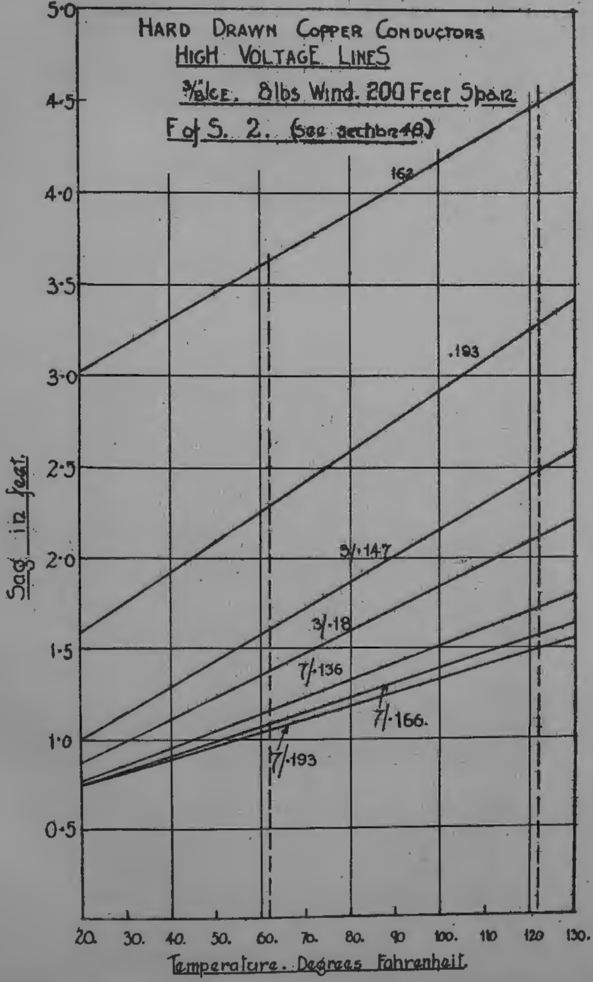

HARD DRAWN COPPER CONDUCTORS
HIGH VOLTAGE LINES
3/8" Ice. 8lbs Wind. 200 Feet Span
F of S. 2. (see section 48)
.162
.193
3/.147
3/.18
7/.136
7/.166.
7/.193
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
Sag in feet.
20.
30.
40.
50.
60.
70.
80.
90
100.
110
120
130.
Temperature. Degrees Fahrenheit.

PLATE 61.

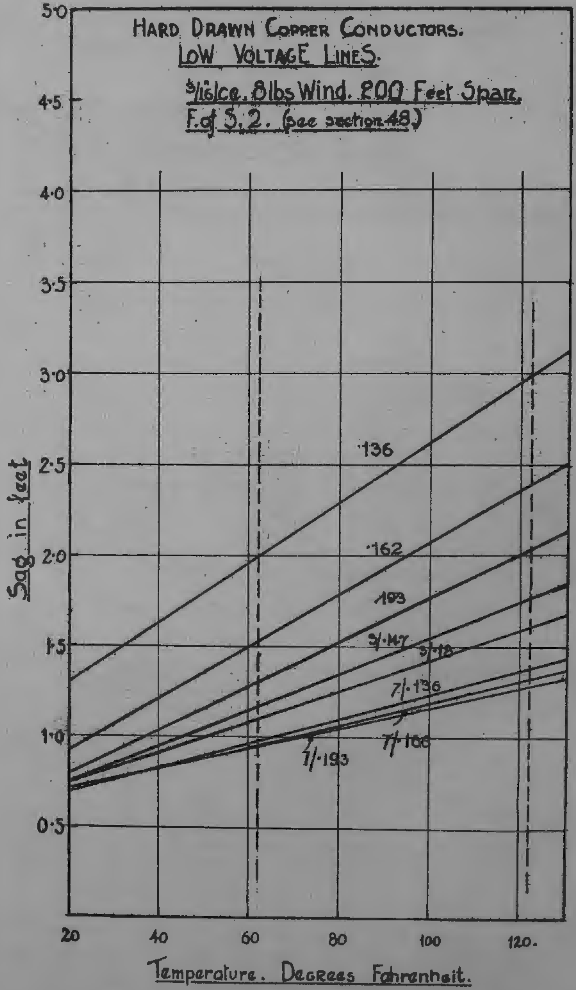

HARD DRAWN COPPER CONDUCTORS.
LOW VOLTAGE LINES.
3/16 Ice. 8lbs Wind. 200 Feet Span.
F. of S. 2. (see section 48)
Sag in feet
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
Temperature. Degrees Fahrenheit.
20
40
60
80
100
120.
·136
·162
·193
3/·147
3/·18
7/·136
7/·160
7/·193

Plate 62.

TERMINATION OF D.C. 3-WIRE SERVICE.

PLATE 63.

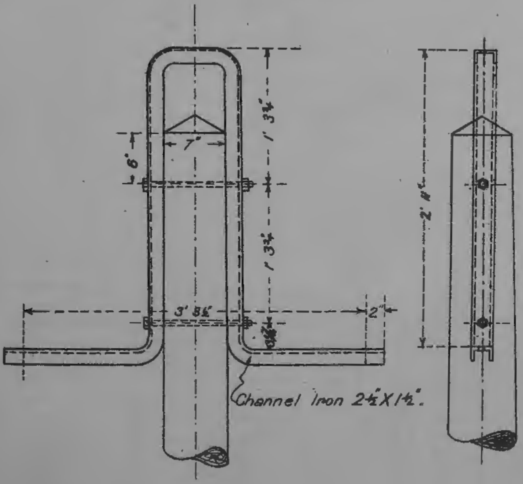
BRANCHING OF D.C. 3-WIRE SERVICE FROM A DISTRIBUTOR.

[To follow plate 63.

Plate 64.

BRACKET FOR 3 - PHASE LINE.

(See Section 49.)

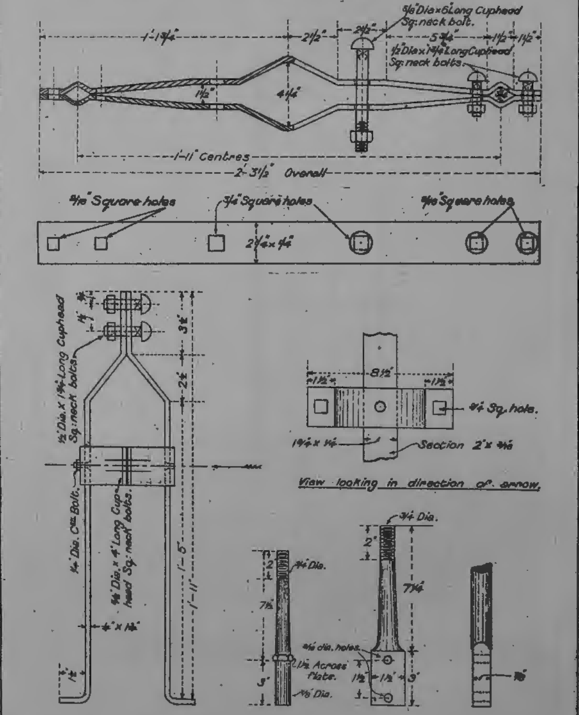


P 3895

Plate 65.

(See Section 49)

BRACKET FOR 3-PHASE LINE.



P3585

specified clearance from ground, and it is assumed to occur at 122° F. which is taken as the maximum summer sun temperature in Great Britain. The value can be obtained from Pls. **60** and **61**. It may be noted, however, that for H.V. conductors up to 0·1, and for L.V. conductors up to 0·05, the *oblique* sag at 22° F. under basic loading conditions is greater than the vertical sag in still air at 122° F.

6. **Length of span.**—Providing that the correct sag is allowed, conductors may be erected on any length of span with equal safety. But as the insulators are the weakest points on the line, from an electrical point of view, the longer the spans the better ; moreover, for lines on private property, the fewer the wayleaves the better. As the length of span increases, however, so must the height and strength of the supports and the spacing of the conductors, and naturally the weight and cost go up as well. Considered theoretically, there will always be a particular length of span for which the product of cost per support and number of supports is a minimum, and this " most economical span " must be aimed at in long E.H.V. transmission ; but for the comparatively short lines at moderate voltages used for military purposes the question of economical span seldom needs consideration, and short spans of the order 150–250 feet are generally most suitable. In L.V. distribution work where the number of wires on a route varies, and there are other points such as street lighting, service connections, &c., to be thought of, it will be found that span lengths of 120–150 feet are most convenient.

49. *Insulator supports.*

1. The amount of drilling and slotting of the pole required to fix the insulator supports should be as small as possible.

The simplest and cheapest form of insulator support for light lines on wooden poles is undoubtedly the SWAN-NECK BOLT screwed directly into the pole (*see* Pls. **62** and **63**). This method of construction can be used for the rapid work that is necessary on active service, and was used by the Germans in the 1914–1918 War, for voltages up to 15,000. It can be employed conveniently for branch distributors when there is little likelihood of future additions, but for permanent work on main or heavy routes it is not so reliable as those methods which make use of brackets or arms.

2. For simple, 3-phase transmission lines, *brackets* such as those shown on Pls. **64** and **65** can be recommended. That shown on Pl. **64**, which consists merely of a U-shaped structure of channel iron, is a design that was developed in Germany prior to 1914, and it was largely used by the Germans in the 1914–1918 War for transmission circuits up to 45,000 volts.

It certainly has the merit of simplicity, but it is rather heavy and makes very poor use of the material. Moreover, the poles must be bored in order to secure the brackets, and on this account the design shown in Pl. **65** is preferable. It will be seen that this consists almost entirely of strap iron, and no cutting of the pole is required to fix it. It is rather expensive to make by hand, but it is a practicable proposition when turned out by machinery in large quantities.

With either of these brackets separate provision must be made for the earth wire or wires prescribed by the E.C. Regulation (*see* Sec. **56**).

A better type of fitting for general use is that shown on Pls. **66** and **78**, which is fixed to the pole by coach screws (not less than 3½″ × ½″). This type is suitable for all voltages up to 22,000. Pls. **67** and **68** show the bracket in use on L.V. lines. These two plates show a split neutral as required by the old E.C. Regulations, carried on a channel iron cross arm. A single neutral conductor is now sufficient (*see* Sec. **56**).

The most useful sizes of channel are 4″ × 2″ and 3″ × 1½″.

Well-seasoned oak arms such as are used by the P.O. for telegraph lines can be used instead of channel iron section if desired. Arms should be slotted into the pole to a depth not exceeding 1½ inches, and secured by means of ⅝-inch or ¾-inch bolts.

Modern practice in distribution work, however, favours the vertical arrangement of conductors, as it is more convenient for tappings, and if the neutral conductor is at the bottom, no special guarding arrangements are necessary.

Pl. **69** shows the design adopted by the Shropshire, Staffordshire, and Worcestershire Power Co. for their distribution lines at 3,300 volts and 400 volts on the same pole.

Pl. **70** gives details of the pole ironwork.

50. *Insulators.*

1. The materials used for insulators are **porcelain, glass,** and **various patented compounds.** The last named, though possessing good mechanical characteristics, have not been used extensively, and British engineers favour porcelain. **Glass,** which is much cheaper than porcelain, is very largely used on the continent, and some continental engineers will use nothing else for voltages up to 20,000V. American engineers prefer porcelain to glass on account of its higher mechanical and dielectric strength.

B.S. Specification No. 137 for **porcelain insulators** states that they shall be made of sound material, free from defects and thoroughly vitrified so that the glaze is not depended upon for insulation, and that the glaze shall be

[To face p. 242.

Plate 68.

TWO TYPES OF IRON BRACKET FOR WOODEN POLES. (See Section 49.)

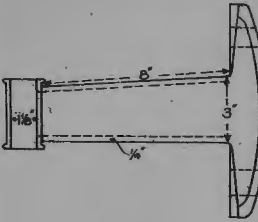


Fig. 1.

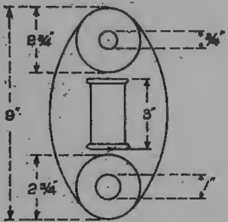


Fig. 2.

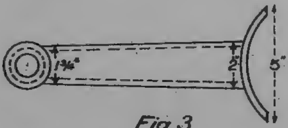


Fig. 3.

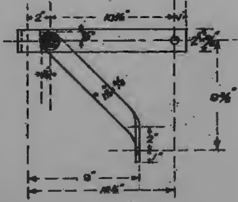


Fig. 4.

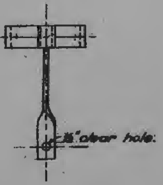


Fig. 5.

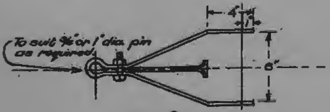


Fig. 6.

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PLATE 67.

A POLE CARRYING 3-WIRE D.C. DISTRIBUTOR AND SWITCH WIRE.

(2-Wire Service Off.)

A POLE CARRYING 3-PHASE 4-WIRE DISTRIBUTOR AND SWITCH WIRE.

[To follow plate 68.

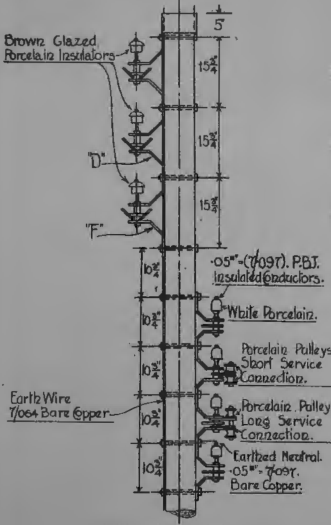
PLATE. 69.

DESIGN FOR HIGH VOLTAGE AND LOW VOLTAGE LINES ON SAME POLE.

(See Section. 49.)

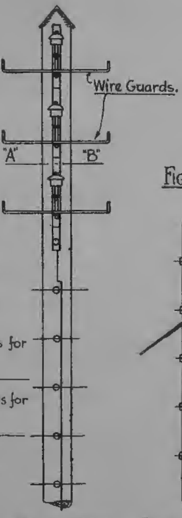
Shropshire, Staffordshire & Worcestershire Electric Power Company.

FIG. 1.



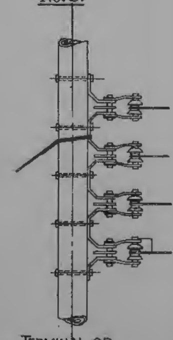
SIDE ELEVATION.

FIG. 2.



END ELEVATION.

FIG. 3.



TERMINAL OR ANGLE POLE.

PLAN AT "A".B" LOOKING DOWN.

Note:-

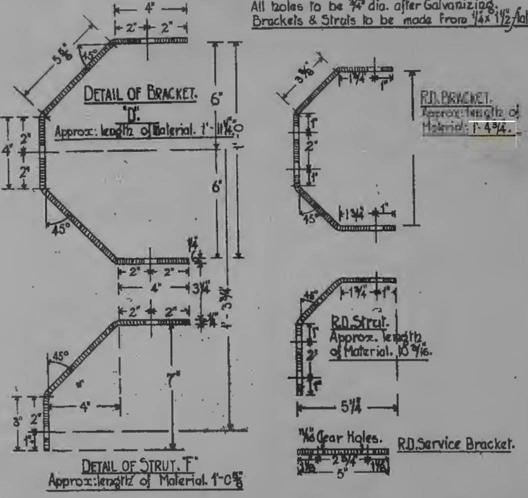
For Details of Fittings see PLATE. No:- "DETAILS OF FITTINGS FOR COMBINED POLE."

PLATE. 70.

DETAILS OF FITTINGS FOR COMBINED POLE.

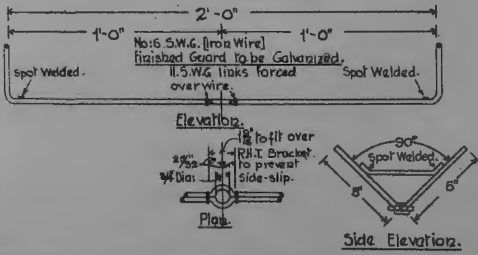
(See Section 49.)

All material to be galvanized.
All holes to be ¾" dia. after Galvanizing.
Brackets & Struts to be made from ¼" x 1½" flat.



Scale: 3 Inches to 1 Foot.

R.H.T. Guard for Line Pole.



brown and shall cover all exposed parts of the insulator. The object of the glazing is to present a smooth surface to dirt deposit, so that the insulator can be washed clean by rain.

2. Insulators for use on H.V. lines are subjected to severe electrical and mechanical tests (*see* B.S. Specification No. 137), of which the following table is indicative :—

Tests of pin-type porcelain insulators.

Recommended maximum working voltage. (i)	Minimum voltage at which insulator will		
	Spark over dry. (ii)	Spark over under artificial rain. (iii)	Puncture under oil. (iv)
kV.	kV.	kV.	kV.
3/3·3	38	16	68
6/6·6	44	22	80
10/11	53	30	95
20/22	74	50	130
30/33	95	70	170

The *British Standard Rating* is based on the figures in column (iii).

In situations near the coast or in manufacturing areas, subject to deposits of salt, soot, &c., it may be advisable to use an insulator of a higher standard rating than is indicated in the above Table.

A mechanical factor of safety of 2½, based on the yield point, is specified, and, in the case of pin insulators, it is assumed, for purposes of mechanical design, that the maximum working load is applied at right angles to the axis of the pin.

3. The following types of insulator are in general use, viz.: **Pin insulators, tensioning insulators** and **suspension insulators,** but the last named are only needed for voltages exceeding **30kV,** and will not be considered further. *Shackle insulators* were largely used in the past for terminating heavy cables, but their use is not recommended above 3,000 volts.

4. **Pin insulators.**—For L.V. systems, the ordinary double-shed insulator (Pl. **71**, Fig. 1), as used in telegraph work, is thoroughly efficient, and has been used with success, in emergencies, for voltages up to 3,000V; but for M.V. and H.V. lines an improvement is effected by the adoption of the type shown on Pl. **71**, Fig. 2, there being no narrow dark openings to be taken possession of by insects. Over 3,000V, a triple-shed insulator, such as shown on Pl. **71**, Fig. 3, is required, whilst with over 20,000V such a thickness

of porcelain is required that it is necessary, to ensure sound results, to make up the insulator in two parts cemented together.

5. Methods of fixing insulators to pins.—Many different means have been employed for fixing insulators to their pins, including direct-screwing, cementing, cementing in a separate metal thimble into which the pin is screwed, and plaster-fixing. The desirable fixing is a detachable one, which permits of the insulators and pins being transported and handled separately, and of the insulators being readily replaced. Direct-screwing and the use of the metal thimble both possess this advantage.

For high voltages **direct-screwing** is not desirable from the electrical standpoint, owing to the sharp edges and small air-gaps between metal and porcelain, but for the comparatively low voltages of military work it is, taking into consideration detachability, ease of erection, and cheapness, the best method to employ. The pin should not, however, be screwed into the insulator without a rubber washer at the head, and care should be taken that the insulator is not strained by overscrewing.

Cementing makes a good sound job for H.V. porcelain insulators, though detachability is sacrificed. Good Portland cement (preferably in accordance with B.S. Specification No. 12), without any trace of magnesium, should be used, and care should be taken that there is a good cushion of cement between pin and porcelain, and that the former is correctly centralized in the latter. The setting takes at least 48 hours, and on no account should the insulator and pin be handled until 24 hours after fixing. Cementing in a **metal thimble** (*see* Pl. **72**, Fig. 1) is recommended as being about the best method of fixing a H.V. insulator. It has the advantage that the delicate part of the work can be done in a workshop, or even by the makers of the insulators, whilst erection and renewal are quite simple matters.

Plaster-fixing, recommended by the French firm, Messrs. Charbonneux et Cie., as the *only* reliable method of fixing for glass insulators, is as good as, or even better than, cementing for porcelain insulators, because all possibility of corrosion of the pin by impurities in the cement is obviated. The fixing mixture consists of plaster, glue, and water, and not more than about 8 lb. should be mixed at a time, because setting commences about 40 minutes after mixing. A good quality of glue, melted to the viscidity used by joiners, should be mixed with water in the proportion of about 1 part of glue to 200 parts of water, and the proportion of plaster added should be such that, when ready for use, the consistency is that of soft putty. In fixing, the cavity of the insulator is first

TYPES OF INSULATORS.

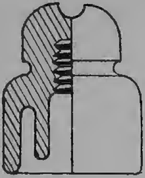


Fig. 1.—Double-Shed.

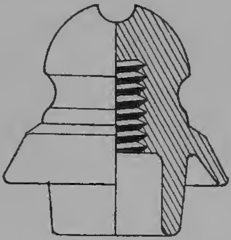


Fig. 2.—Improved Double-Shed.

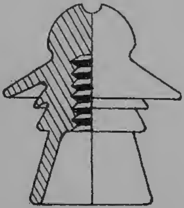


Fig. 3.—Triple-Shed.

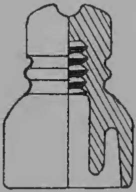


Fig. 4.—Double-Groove.

Fig. 5.—Tensioning.

FIXING INSULATORS.

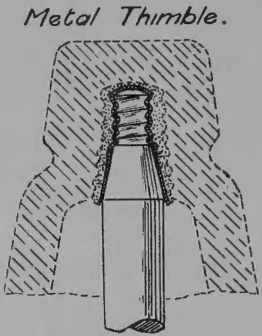


Fig. 1.

Fig. 2.

of all half-filled with a sausage of the mixture ; then the pin is pushed in as far as it will go, and held in position while the plaster is well rammed home by means of a small tool (*see* Pl. **72**, Fig. 2) made out of a thick piece of wire. The insulator must then be placed on a drier and left for about an hour, after which it can be handled carefully. It can be placed in position after a period of 1 to 2 days, and this quick setting makes the method particularly useful for quick construction on active service.

6. Experts differ as to whether it is better to *bind the wire in* to the top groove or the side groove of the insulator. It is recommended that the side groove should be used, except for long straight runs of H.V. line and for all moderately heavy conductors, as the lineman cannot hold them up when binding-in. At bends and corners the side groove must be used, with the insulator *inside* the bend of the wire.

For double terminations in L.V. work, such as at crossings or where joints occur, *double-groove insulators* (*see* Pl. **71**, Fig. 4) are obtainable.

7. **Tensioning insulators** (Pl. **71**, Fig. 5) are used for anchoring conductors and negotiating considerable angles, when the side strain on the pin would be excessive. In the past, shackle insulators have been used in such cases, but these are now practically obsolete for voltages above 3,000, and have been replaced by the disc type, either interlinked or metal hooded. For very high voltages it is necessary to have several insulators linked together in series.

Examples of shackle insulators in use can be seen on Pls. **76**, **84**, and **90**.

51. *Disposition and spacing of conductors.*

1. The **equilateral triangle formation** is the best arrangement for main transmission lines to secure equality of inductive voltage drop, but this requirement does not necessitate rigid adherence to any particular arrangement, and it has little bearing on the matter in connection with D.C. or low-voltage A.C. distribution lines. With the latter the disposition of the wires is entirely determined, subject to the fulfilment of the E.C. Regulations, by considerations of *ease of distribution and wiring* (minimum number of crossings, convenient arrangement of house services, &c.).

2. The **spacing of conductors** carrying D.C. is dependent upon mechanical considerations only, *i.e.*, length of span, sag, weight, and arrangement of wires. Lines run on the same level will naturally need a greater clearance than if arranged in a staggered formation, whilst heavy lines under considerable

mechanical tension require less clearance than light lines at a small tension.

With A.C. the spacing affects the voltage regulation, and, in order to keep the voltage drop within low limits, the lines should be as close together as possible.

This applies more particularly to L.V. lines carrying large currents (*see* Sec. **34**). For H.V. lines, mechanical considerations again predominate, up to say 66,000 volts. At higher voltages loss by corona may have to be considered.

Trouble is sometimes experienced on H.V. lines, and to a lesser extent on L.V., when wires are placed directly one below the other, due to accumulation of sleet and ice, and to birds settling on the wires. On the other hand, the vertical arrangement simplifies branch connections, and no special guard wires are required on L.V. and M.V. lines if the earthed neutral conductor is at the bottom. It may be said that the advantages of the vertical arrangement outweigh the disadvantages on L.V. and M.V. lines and on H.V. lines up to 3,300 volts.

The horizontal arrangement of conductors usually permits a shorter pole to be used, but the possibility of conductors swinging together in strong winds must then be considered.

As a general rule for H.D. copper conductors, when placed in the same *horizontal plane*, the spacing should not be less than the *sag in still air at* 62° F., and when in the same *vertical* plane, a spacing not less than 1 foot per 100 feet of span should be allowed.

For H.D. aluminium conductors, somewhat larger spacings should be allowed owing to the greater ratio of wind load to weight, and the greater surface for the deposit of ice.

3. *Clearance from pole and pole iron-work.*—The following *minimum* values should be allowed :—

Up to	660 volts	..	4 inches.
,,	6,600 ,,	..	6 ,,
,,	11,000 ,,	..	9 ,,
,,	22,000 ,,	..	10 ,,

4. *Clearance of line conductors, &c., from ground.*—The following figures are fixed by the E.C. Regulations as the minimum clearances at 122° F. :—

(1) (*a*) *H.V. Line Conductors.*	
In all situations up to 66,000 volts ..	20 feet.
(*b*) *L.V. Line Conductors.*	
i. Public road crossings	19 ,,
ii. Situations inaccessible to vehicular traffic	15 ,,
iii. All other positions	17 ,,

(2) *Clearance of Earth Wire and Auxiliary Conductors from Ground.*

(*a*) *H.V. Lines.*	
i. When erected across a public road, canal, or railway	20 feet.
ii. Situations inaccessible to vehicular traffic	15 ,,
iii. All other positions	17 ,,
(*b*) *L.V. Lines.*	
i. Public road crossings	19 feet.
ii. Situations inaccessible to vehicular traffic	15 ,,
iii. All other positions	17 ,,

52. *Poles.*

1. Poles or masts for supporting the conductors are made of various materials, and are made up in various ways according to the size and number of wires to be carried, the nature of the ground, and the general conditions of service.

Generally speaking, **wood poles** are much cheaper in first cost than **steel** or **concrete poles**, and for military purposes it will seldom be necessary to employ anything else. For local distribution systems at L.V. and for transmission lines with spans of moderate length (up to about 200 feet) they are eminently suitable.

Regarding the use of wooden poles for E.H.V. transmission lines, Still, in *Electric Power Transmission*, states :—

> Although steel poles, or steel towers, will generally be found more economical than a wood pole line for voltages above 44,000 on account of the heavier insulators, wider spacing between conductors, and generally greater height of support, it does not follow that wood poles or wood-pole structures may not prove economical, even for comparatively high voltages, in countries where suitable timber is plentiful and the ready means of transportation and erection of steel towers are wanting.

All wooden poles should have their natural butts sawn off square after the timber has been felled. Untreated poles have a short useful life varying from about 5 years for pine up to 10 to 12 years for cedar and chestnut. The life of poles depends a great deal on the time of the year in which trees are felled, the best time to cut being when the tree carries the least amount of sap, *i.e.*, from November to April. Untreated poles are not likely to be used under peace-time conditions, since by impregnating the poles, after seasoning, with various preservative compounds their life is very largely increased. The best preservative process is creosoting, whereby heated creosote (12 lb. per cubic foot) is forced into the timber under a pressure of 100 lb. per square inch.

In the Rüping method of creosoting about two-thirds of the creosote is subsequently withdrawn, leaving the cells of the wood only coated with the oil; the efficiency is not impaired thereby, and the cost is materially reduced.

If a pole is erected within a few months after creosoting, a life of from 20 to 30 years may be expected. All the trimming and slotting of the pole is better done before creosoting, and any recess cut in a pole afterwards should be painted with a mixture of coal-tar and creosote. The top of a pole should be protected from the destructive effects of the sun and rain by a galvanized iron roof.

2. **Single wood poles** have the advantages of simplicity and cheapness, and will satisfy most military requirements. Table H gives particulars of British Standard Poles. For further particulars, *see* B.S.S. 139.

3. **Calculations for size of pole required.**—For simple supporting poles in a straight line the only loading to be considered is the transverse wind pressure on the conductors and other wires on the pole, and on the pole itself.

Let H = height from ground level to point of loading, in inches.
A = length of pole above point of loading, in inches.
Dg = diameter of pole at ground line, in inches.
P = wind load on all the conductors and wires on the pole.

Then we have *bending moment* on pole at ground line $= PH$ lb.-in. due to wind load on conductors and wires, plus $(H + A)\left(\frac{H + A}{2}\right)Dg\,\frac{8}{144}$ lb.-in. due to wind load of 8 lb. per square foot on the pole itself.

This assumes that the pole is of uniform diameter, whereas it actually has a taper of about 1 in 100, but the error introduced is small and on the safe side.

The **moment of resistance** of the pole at the ground line

$$= \frac{\pi \times Dg^3 \times f}{32} \text{ lb.-in.}$$

Assuming $f = 7{,}800$ lb. per square inch, and allowing a Factor of Safety of 3·5 as required by the Electricity Commissioners' Regulations, we get, equating the Bending Moment to the Moment of Resistance, *Safe Working Load on pole,*

$$= P = 219\,\frac{Dg^3}{H} - \frac{1}{36} \cdot \frac{(H + A)^2}{H} \cdot Dg.$$

Now assume four 0·193 H.D. copper wires (3 conductors, one earth wire) on a H.V. line with span length 200 feet.

If the conductors are arranged at the corners of an equilateral triangle of 3 feet side, with two conductors on a cross arm and the other a few inches above the top of the pole on a cap fitting, the centre of pressure of the wind load on wires will be approximately on the line passing through the point of attachment of the lower conductors, which will be about 2 feet from the top of the pole.

From Sec. **48**, the wind load per foot run of conductor $= 0{\cdot}629$ lb.

$\therefore$ $P = 0{\cdot}629 \times 200 \times 4 = 503{\cdot}2$ lb.

$H = 20$ (required ground clearance) $+ 3{\cdot}3$ (vertical sag in still air at 122° F.).

$= 23{\cdot}3$ feet $= 279{\cdot}6$ inches.

$H + A = 279{\cdot}6 + 24 = 303{\cdot}6$ in.

Substituting known values in formula for P, we get

$Dg^3 - 11{\cdot}7Dg = 642$; whence $Dg = 9{\cdot}1$ in. approx.

4. **Depth of pole in ground.**—An old rule of thumb gives one-sixth the overall length for the buried depth of single wood poles. It is more logical, however, to base the depth upon the diameter at ground level, and in good soil the following formula gives satisfactory results :—

$$h = 0{\cdot}4D + 1{\cdot}4$$

in which h = depth in feet and D = diameter of pole in inches at ground line.

In our example

$$h = 0{\cdot}4 \times 9{\cdot}1 + 1{\cdot}4 = 5{\cdot}04 \text{ feet.}$$

Overall length of pole required

$$= 25{\cdot}3 + 5{\cdot}04 = 30{\cdot}34 \text{ feet.}$$

Reference to Tables **G** and **H** shows that the nearest standard pole is 32 feet by 9 inches, which would meet the requirements if the span length were slightly reduced. If the length is reduced to 180 feet, a 30 feet by $8\frac{3}{4}$ inches standard pole will do. When indenting for poles, it is advisable to ask for a few of the next larger and a few of the next smaller size to allow for uneven ground.

Table **G** gives maximum safe working loads that can be applied to single and A poles at a point 2 feet from the top to comply with E.C. Regulations. When P and $(H + A)$ are known, the required diameter (D) at ground line can be found directly from this table.

If the buried depth is then added, the nearest standard pole can be selected from Table H. It will be noted that the standard poles are rated on their diameter at a point 5 feet from the butt, and this point will not always coincide with the ground line. Moreover, the centre of loading may never be exactly 2 feet from top of pole. Nevertheless,

TABLE G.—*Strengths of Wood Poles.*

The safe load that may be applied 2 ft. from the top of the pole, taking a maximum fibre stress of 7,800 lb./sq.", allowing for wind pressure on pole itself and providing a factor of safety of 3·5, as required by E.C. Regulations.

Height of pole out of ground, in feet.	Single poles. Net safe load in lb.															" A " poles. Net safe load in lb.										
	Diameter of pole at ground line, in inches.															Diameter of pole at ground line, in inches.										
	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12	12½	13	8	8½	9	9½	10	10½	11	11½	12	12½	13
18	206	269	334	420	530	643	770	913	1073	1250	1446	1662	1869	2146	2417	—	—	—	—	—	—	—	—	—	—	—
20	175	228	296	372	460	559	673	798	940	1096	1268	1457	1662	1887	2134	—	—	—	—	—	—	—	—	—	—	—
22	152	202	260	330	410	499	600	713	839	979	1135	1306	1493	1695	1914	2016	2428	2894	3414	3994	4634	5342	6118	6965	7886	8880
24	131	175	226	291	363	443	534	636	750	877	1018	1174	1343	1528	1725	1818	2192	2614	3085	3612	4193	4836	5542	6310	7147	8162
26	112	152	199	256	322	396	478	571	675	790	919	1062	1216	1385	1566	1651	1994	2380	2811	3292	3824	4413	5059	5763	6530	7356
28	—	—	—	227	289	355	430	516	610	717	836	967	1109	1264	1430	1510	1825	2186	2577	3020	3510	4053	4649	5299	6007	6757
30	—	—	—	—	259	319	389	467	554	652	762	884	1016	1159	1313	1388	1679	2007	2377	2785	3240	3743	4297	4899	5555	6262
32	—	—	—	—	232	288	352	424	505	595	698	811	934	1068	1211	1280	1551	1856	2200	2580	3003	3474	3989	4552	5163	5824
34	—	—	—	—	207	260	319	386	461	545	641	746	861	987	1119	1188	1438	1725	2045	2400	2796	3237	3719	4246	4818	5434
36	—	—	—	—	—	—	289	352	422	499	590	689	796	914	1038	—	—	1606	1907	2242	2613	3025	3480	3975	4514	5093
38	—	—	—	—	—	—	—	320	385	459	543	636	738	849	965	—	—	—	1783	2093	2447	2837	3266	3733	4240	4787

TABLE H.—*Sizes and Weights of standard creosoted Fir Poles.*

LIGHT.					MEDIUM.					STOUT.				
Length.	Diameter at top.		Minimum diameter at 5 ft. from butt end.	Approx. weight.	Length.	Diameter at top.		Minimum diameter at 5 ft. from butt end.	Approx. weight.	Length.	Diameter at top.		Minimum diameter at 5 ft. from butt end.	Approx. weight.
	Minimum.	Maximum.				Minimum.	Maximum.				Minimum.	Maximum.		
Ft.	In.	In.	In.	Cwt.	Ft.	In.	In.	In.	Cwt.	Ft.	In.	In.	In.	Cwt.
16, 18	5	5¾	6	1·45	—	—	—	—	—	—	—	—	—	—
20	5	5¾	6	1·75	—	—	—	—	—	—	—	—	—	—
22	5	5¾	6¼	2·0	—	—	—	—	—	—	—	—	—	—
24	5	5¾	6½	2·5	24	5½	6¾	8	3·25	—	—	—	—	—
26	5	6	6¾	2·85	26	5¾	7	8¼	3·75	—	—	—	—	—
28	5	6	7	3·3	28	5¾	7	8½	4·05	—	—	—	—	—
30	5	6	7¼	3·65	30	6	7¼	8¾	4·75	30	7½	9½	10¾	7·0
32	5	6¼	7¼	4·05	32	6	7¼	9	5·4	32	7½	9¾	11	7·9
34	5	6¼	7½	4·75	34	6	7½	9¼	6·05	34	7½	9¾	11¼	9·1
36	5	6½	7¾	5·2	36	6	7½	9½	6·9	36	7½	9¾	11½	10·5
40	5	6½	8	6·0	40	6	7½	9¾	8·1	40	7½	9¾	12	12·0
45	5¼	6¾	8¾	7·0	45	6½	8	10¾	9·9	45	7¾	10	13	14·6
50	5¼	7	9½	8·75	50	6½	8¼	11½	12·05	50	7¾	10¼	13¾	16·9
55	—	—	—	—	55	7	8¾	12½	14·5	55	8	10½	14¾	19·65
60	—	—	—	—	60	7	8¾	13¼	16·95	60	8	10½	15½	22·75
65	—	—	—	—	65	7	9	14	20·4	65	8	10½	16¼	26·8
70	—	—	—	—	70	—	—	—	—	70	8	10½	17	31·05
75	—	—	—	—	75	—	—	—	—	75	8	10½	17¾	35·5
80	—	—	—	—	80	—	—	—	—	80	8	10½	18¾	40·25
85	—	—	—	—	85	—	—	—	—	85	8	10½	20	45·5

for ordinary purposes the size of pole can be determined with sufficient accuracy by the method indicated above.

5. **Setting poles.**—The pole hole should be dug somewhat in the shape of a stepped trench and should be as narrow as possible laterally, so as to get firm earth against the normal direction of the load; the length in the direction of the wires should be just sufficient to permit of necessary excavation. When filling in, the earth must be thoroughly well rammed, and it is a good plan to put two layers of broken stone round the pole, one at the butt and the other at about one-third of the depth. In soft ground it may be necessary to fix one or more foundation blocks to increase the stability. If one only is fixed to minimise excavation, the most effective position is at one-third the depth. But with heavy lines in soft ground, it is better to fix two blocks, one at the butt and the other at one-third the depth, the area of the upper block being about double that of the lower.

It is inadvisable to mount a wooden pole in concrete, but there are some cases in which such a method of fixing becomes necessary.

Poles should be dressed prior to erection.

6. **Compound wood poles.**—When the conductors are of large cross-section, or where a large number of conductors have to be carried, compound poles may be necessary.

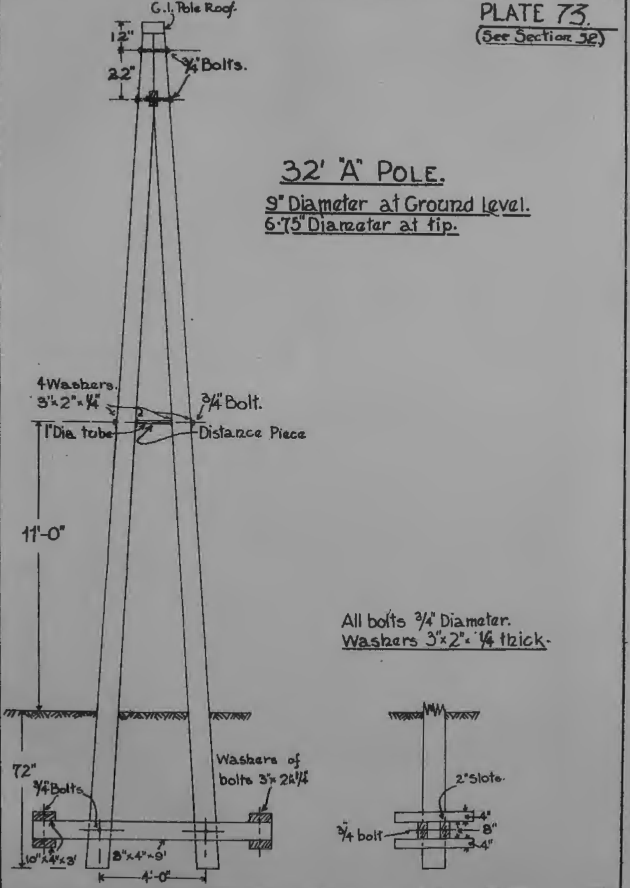
" A " poles.—The construction of these poles is shown in Pl. **73**, the legs being splayed at approximately 1 in 8.

Examples of " A " poles in actual use will be found in Pls. **67**, **68**, and **74.** It will be noted that the bolts for securing the scarfed ends of the two poles have been utilized as one of the fixings of the brackets. This is not good practice.

If fixed rigidly in the ground, the strength of an " A " pole may be taken as 4½ times as great laterally as that of a single pole comprising one of its members. But as the factor of safety for wood poles has now been reduced from 10 to 3·5, more attention must be paid to the design of the foundations than was formerly necessary. The design shown in Pl. **73** is satisfactory. Heavier poles require special consideration, the weakest point being the bolt attachment of the brace blocks. The wind pressure on " A " poles is taken as 1½ times that on a single pole.

" H " poles have the advantage over single and " A " poles of presenting a greater area for the accommodation of a large number of wires, and the fixing of cross-arms can be made more secure. They are particularly suitable for terminal poles where the wires have to be spaced well apart, and switchgear, cable terminating boxes, &c., have to be fitted. Moreover, they are sometimes necessary at angle

PLATE 73.
(See Section 32)



32' "A" POLE.

9" Diameter at Ground Level.
6·75" Diameter at tip.

All bolts 3/4" Diameter.
Washers 3"×2"×1/4 thick.

P3895

[*To follow plate* 73.

A POLE ON A D.C. 3-WIRE SYSTEM.

[*To follow plate* 74.

H.V. TERMINAL POLE (TIDWORTH).

H.V. TERMINAL POLE (BULFORD).

and terminal poles on heavy lines when single poles have insufficient buckling strength.

Examples of " H " poles in use are shown in Pls. **75** and **76.** The strength of " H " poles depends upon the methods of bracing, but as usually constructed with one set of trussing tackle they may be considered to be about 3½ times as strong as single poles. The trussing tackle is a standard commercial article, but when ordering it is necessary to specify diameter of poles and distance between centres of poles. The foundations should be designed on the same lines as those of " A " poles (*see* Pl. **73**).

The wind pressure on " H " poles is taken as 1¾ times that on a single pole.

Where there are a large number of junctions as may occur at terminal poles, feeding points, &c., structures composed of 4 poles braced together are often used. Examples of this construction are given on Pls. **91** and **92.**

Rutter poles may be briefly referred to. They consist of two similar poles bolted together parallel to one another, with hard wood scarf blocks slotted into the poles at intervals to take the shear stress. As usually constructed with the poles about four inches apart at the ground line, the lateral strength is about eight times that of a single pole. That is the ratio of lateral to longitudinal strength is 4 to 1, which is the limit imposed by the E.C. Regulations. Foundation blocks are used, one at the butt and another at about one-third the depth, to give the necessary resistance to overturning. The pole is the strongest type yet developed, but its construction is really a factory job, and, moreover, it is patented. If such poles are used, they will normally be purchased ready made and transported complete, except for the foundation blocks.

7. Iron and steel poles are usually of the tubular or lattice-girder types. The former type is largely used in tropical climates where wooden poles would be subject to the ravages of insects, whilst the lattice-girder type is used mainly for heavy long-distance lines. Unless they are galvanized, iron and steel structures require two coats of paint about every three years, and their first cost to manufacture and erect is more than that of wooden poles, but, owing to the increasing scarcity of forest timber, the difference in first cost is likely to become less in future. The life of a steel pole may be taken as 50 years under favourable conditions, but is often much less in manufacturing districts. The factor of safety laid down for steel poles in the E.C. Regulations is 2·5, based upon the elastic limit.

Attention is drawn to B.S.S. 134 for tubular steel poles for telegraph and telephone purposes. Many of these poles are suitable for power lines. Two types of multiple section poles are standardized, made up of sections 8 feet long. These are obviously the best types for use abroad. The Bates expanded steel pole has been used in some of the colonies, and is stated to be quite as good as the tubular steel poles and much cheaper. It is of American origin, however, and does not appear to be manufactured in Great Britain.

8. **Reinforced concrete poles** have only been used a few years, but are generally satisfactory. Iron or steel embedded in concrete will last indefinitely without deterioration. Their great weight is a disadvantage, but, when transport facilities are good and the line projected is permanent, they are satisfactory poles to adopt, since the maintenance cost is negligible. There are at present no data available from which to estimate the life of these poles, but it is certainly very great.

9. It may be noted that steel and reinforced concrete poles are less liable to destruction by lightning than wooden poles.

For details concerning steel and reinforced concrete pole construction, reference should be made to one of the books quoted at the end of this chapter.

10. **Angle and terminal poles** must be provided with *stays* or *struts*, the former being preferable on account of the greater ease of fixing, lower cost, and better general appearance. On a long straight line it is advisable to provide both longitudinal and cross stays at every fifth pole.

The line of a stay or strut at an angle should divide equally the angle between the line wires; the point of attachment should be as near as possible to the point of the resultant loading on the pole, although on H.V. lines it should be below the lowest H.V. wire.

53. *Stays and struts.*

1. **Stays.**—The most efficient position in which a stay can be fixed is obviously such that the stay wire is at right angles to the pole, but this is in most cases impossible. Generally speaking, for stays at angles the base need not exceed half the height of the resultant point above the ground, whilst for stay on terminal poles it should equal that height.

The Service pattern of stay wires (*Wires, stay, BB*) are composed of 4 or 7 strands of galvanized iron wire.

Allowing a Factor of Safety of 2·5 as required by the E.C. Regulations, the maximum safe working loads of the most useful sizes for power line work are 4/0·16, 2,240 lb.; 7/0·16, 3,920 lb.

The lower end of the stay is made off to a stay rod, ⅝ in.

[To face p. 254.

PLATE 77
(See Section 53)

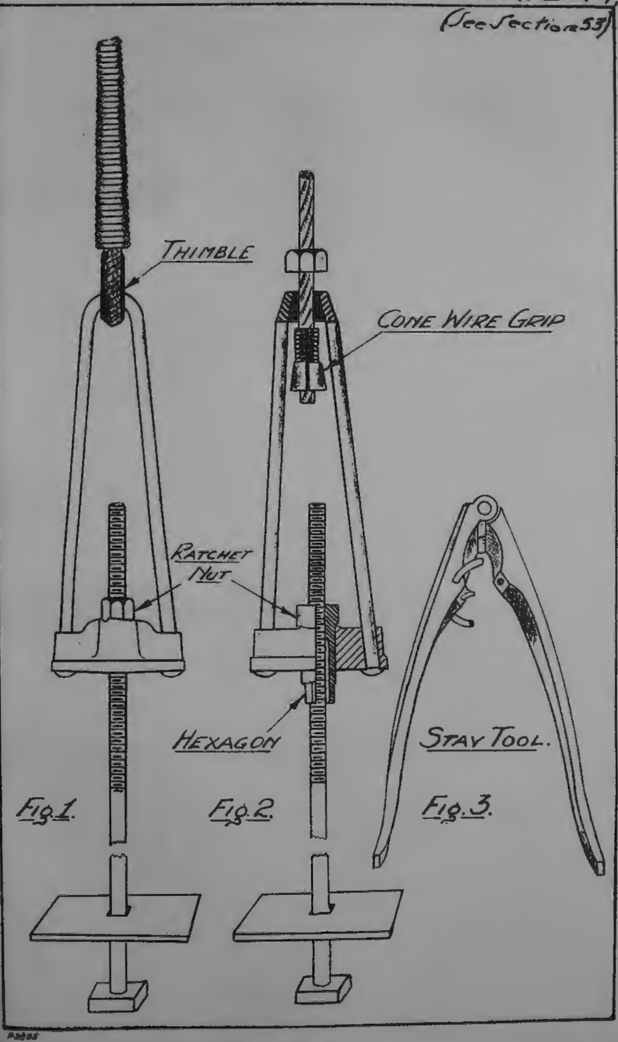
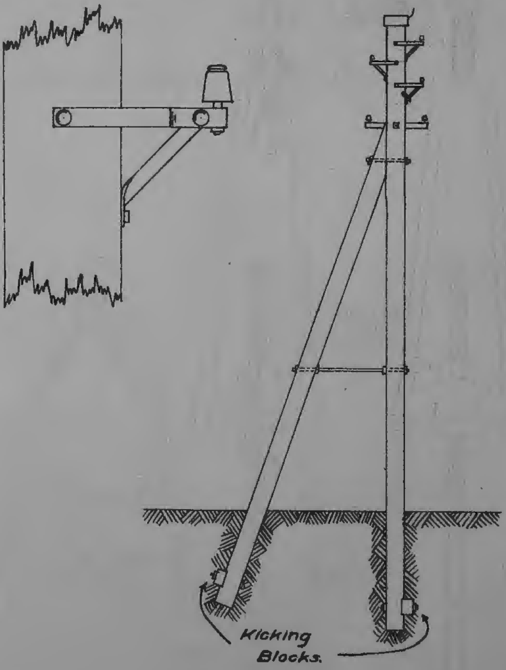


PLATE 78.

(See Section 53.)

STRUTTED POLE.



in diameter for 4/0·16 stay wire and ¾ in. diameter for 7/0·16 stay wire. (*Rods, stay* 6 *ft. by* ⅝ *in. and* 8 *ft. by* ¾ *in.*)

The stay rod terminates in a stay tightener (*see* Pl. **77**). The old pattern is shown in Fig. 1, and an improved design in Fig. 2. Stay plates are also a Service store (*Rods, stay, plates*), but they are not so convenient for general use as a wooden stay block about 10 inches by 5 inches in section and 2 to 4 feet long, according to the load on the stay. Creosoted wooden sleepers, cut in half, make serviceable stay blocks. Cut surfaces should be creosoted.

To attach the stay wire to the thimble of the stay tightener, a special tool, known as *Tool, stay*, and shown on Pl. **77**, Fig. 3, is used, and the method of attachment is as follows :—

Bend the stay wire to form two knees from 4 inches to 6 inches apart, according to the size of the thimble, the first of these knees being from 13 inches to 22 inches from the end of the wire, according to the number of wires in the stay.

Then bend the wire between the two knees round the thimble, using the tool to draw it close into the groove. Unstrand the free end, straighten out the wires, pick out one end for the first lap, and loosen the tool while the wire is placed underneath it. Again grasp the remaining wire with the tool, and place them symmetrically parallel with and around the main strand, so that they will bind into it without spoiling its circular shape. Grip with the tool, and revolve the latter with the free wire under the hook on the thimble side of the tool. This wire should make eight laps.

Then treat the third and similar ends in the same way until all are evenly bound round the main stay. The third, fourth, and fifth wires should make seven laps each, the sixth and seventh six laps each. The projecting short ends of each wire (which should not be more than ½ inch long) must be worked in by grasping the splice with the tool (the ends being within the hollow of the tool) and turning the tool over each end until it is worked in.

The top end of the stay wire is attached to the pole by being lapped twice round it, secured by staples, and spliced in the manner just described.

2. A **strut** must be employed where space will not permit of a stay. In fixing a strut, the pole must not be unduly weakened by slotting, the head of the strut must be carefully scarfed to fit the pole, and the surface of the joint covered with a mixture of coal-tar and creosote. The method of fixing is indicated on Pl. **78**. Where there is a likelihood

of horsemen passing between the strut and the pole, the tie rod should be at least 12 feet above ground level. The *kicking blocks* near the bottom of the pole and the strut are strong wood blocks, 3 to 4 feet long, secured by means of bolts in notches cut in the poles.

The angle which a strut should make with the pole is usually decided by the amount of ground available, but, when possible, the principles laid down for stays should be adhered to.

3. **Stay calculations.**—Let P_m lb. be the total maximum wind load per span, T_m the total maximum longitudinal tension, in both cases due to all the conductors and wires on the line under the worst loading conditions at 22° F., θ the angle of deviation of line, $\alpha°$ the angle which the stay wire makes with the ground, and H the height from ground to point (or centre) of loading, then we have

Load on angle pole stay

$$= \frac{P_m + 2\,T_m\,sin\frac{\theta}{2}}{cos\ \alpha}$$

and **Load on terminal stay**

$$= \frac{T_m}{cos\ \alpha}$$

As an example, consider a 20° deviation on the H.V. line of four 0·193 conductors on 200 feet spans dealt with in Sec. **48.**

$P_m = 503{\cdot}2$ lb. ; $T_m = 874 \times 4 = 3{,}496$ lb. ; $sin\ \frac{\theta}{2}$

$= sin\ 10° = 0{\cdot}174$

$H = 23{\cdot}3$ feet.

Assuming spacing of stay rod from foot of pole to be

$$\frac{H}{2} = 11{\cdot}65 \text{ feet,}$$

Then $cos\ \alpha = \dfrac{11{\cdot}65}{\sqrt{23{\cdot}3^2 + 11{\cdot}65^2}} = 0{\cdot}449$

and **Load on stay**

$$= \frac{503{\cdot}2 + 2 \times 3{,}496 \times 0{\cdot}174}{0{\cdot}449} = 3{,}830 \text{ lb}$$

∴ a 7/0·16 stay wire will be required.

Load on terminal stay.

Assume $\alpha = 45°$, *i.e.*, spacing of stay rod from foot of pole = H, then Load on stay

$$= \frac{3496}{cos\,45} = \frac{3496}{0{\cdot}7071} = 4{,}950 \text{ lb.}$$

Two 7/0·16 stays will be required.

The above assumes that the centre of loading on the pole coincides exactly with the point of attachment of stay, and this should always be approximately so in practice.

Note that the poles are subjected to a large direct vertical loading when stays are fixed, and therefore angle and terminal poles should be stouter than the ordinary supporting poles in the line.

The calculations for struts are similar to the above, but as the poles are in tension, foundation blocks must be fixed.

For **strength of anchorages,** see Military Engineering, Vol. III (Bridging), 1928, page 118.

54. *Wiring and jointing.*

1. The first thing to be remembered in wiring is the damage that may result if the *outer skin* of the wire is *scraped or cut.* This has already been explained (Sec. **47**), and steps should always be taken to prevent cables being drawn along roads or over stony ground. Where very heavy cables are concerned, it may be preferable to lay them at the foot of the poles before lifting into position, rollers being placed at intervals to raise them from the ground, though this method is, of course, not possible when H poles, such as that depicted on Pl. **85**, are employed. Wherever the poles will stand the tension, and suitable straining tackle is available, the rollers should be mounted on the arms, and the cable led over from one pole to another. A suitable form of roller is illustrated on Pl. **79**, Fig. 1, and an ordinary snatch block can easily be adapted for the purpose.

The provision of rollers, however, is an elaboration which is not necessary if due precautions are taken to prevent damage to the cable. A very simple precautionary measure is to bind the arms with pieces of old sacking ; the canvas with which the coils of cable are bound when issued is also eminently suitable.

2. The cable should, if possible, be mounted on a *revolving drum*, provided with some sort of brake to prevent it overrunning, and the drum should be mounted in direct line with the poles and at a distance from the foot of the first pole at least equal to the height of the pole. If no drum is available, and the cable has to be paid out from a coil, it should be held in the hands and revolved. *On no account* should the coil be placed on the ground and the cable flaked off ; such a proceeding leads to kinking and caging.

Special attention should be paid to the **drawing-up** of the cables to the proper tension or sag (*see* Sec. **48**). Too great a sag is almost as objectionable as too great a tension. When all the cables have been run over a certain section they are loosely bound-in to the insulators, and then all are properly regulated. A man should be situated up each pole of the section being regulated to ease the cables over the supports, and to ensure that the tensions and sags are equalized in all bays. The number of bays that can be regulated at one time in the straight will vary according to the weight of the cable, &c., and the straining tackle available.

In the case of large cables the sag may be too small for sufficiently accurate measurement, and it will be necessary to use a dynamometer to measure the tension. With smaller cables or wires it will be sufficient to sight through for the sag; for this operation a man is situated up one of the poles in the middle of the section being regulated, and with his eye at a distance below the conductor or support equal to the required sag he lines in the lowest point of the cable as it is drawn up with a mark at a similar level on the next pole.

It is advisable to leave the strain on for about a quarter of an hour before binding-in, and it will frequently be found desirable to give some final adjustment, the general appearance of the line from a little distance being an unfailing indication to the practised eye of correct or faulty regulation.

The sag or stress of one cable only need be set; the others on the route can be regulated to it by eye.

When pulling up to the necessary tension or sag, the lighter cables or wires should be gripped by *Tongs, draw, heavy* (Pl. **79**, Fig. 2). For the heavier cables a clamp, such as is shown on Pl. **79**, Fig. 3, will have to be employed; this clamp should be of the same material as the cable, and it should grip a length of the cable equal to about 12 diameters.

3. A method of *checking the sag* by the natural time of the swing of the line, considered as a pendulum, is given by Kapper (*see* Bibliography at end of chapter). The line is set swinging, and the number of half-swings per minute counted.

$$\text{Then } 12D = \left(\frac{420}{n}\right)^2,$$

where D is the sag in feet, and n is the number of half-swings per minute.

4. **Jointing.**—The jointing of cables and wires is, as with underground cables, a very important part of the construction work, for badly-made joints are an endless source of trouble.

Although soldered joints are naturally the best from a conductivity point of view, clamp connections are used a good deal for copper conductors, as they save labour and are handy for disconnecting purposes when localizing faults.

Whether clamped or soldered joints are used, however, it

PLATE 79.

WIRING APPLIANCES.

(See Section 54.)

Fig. 1.

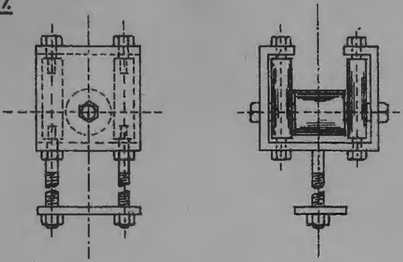


Fig. 2.

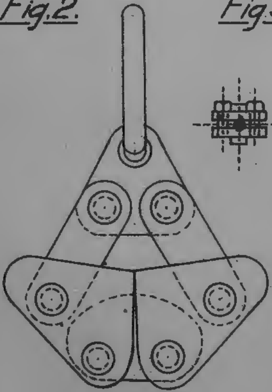
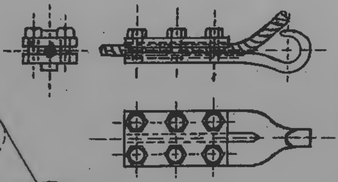


Fig. 3.



is advisable that they should never be subjected to mechanical stress, and this should be made a definite rule in H.V. work.

The heating necessary for soldering seriously reduces the strength of hard-drawn wires.

A cone type of clamp connector can be obtained which is as strong as the wire itself, but the cheaper and more common parallel type is much weaker.

Consequently, it should be so arranged that all jointing is done at the points of support, each length of cable being terminated there, and the tails joined by a clamped joint, a soldered *sleeve joint*, or *twist joint* (for copper cables), a *welded joint* (for aluminium cables up to about 0·2 sq. in.), or a *clamped joint* (for aluminium cables over 0·2 sq. in.).

5. *Copper cables or wires* of large section should be jointed by butting the two ends in a split tinned-copper sleeve of suitable size, and by sweating up solid, exactly as is described for the jointing of the copper conductors of cables (Sec. **43**). For small single-strand and three-strand wires a soldered twist joint (Sec. **43**) may be employed.

6. *Aluminium cables* are best jointed by means of a welded joint, but difficulty will be experienced in getting a satisfactory weld, except by a very skilled man, for cables above 0·2 sq. in. in cross-sectional area.

To make a welded joint proceed as follows :—

Construct a split copper sleeve out of 18 S.W.G. copper sheet ; this should be about 2 to 3 inches long, according to the section of the conductors to be jointed, with a circular orifice in the centre.

This sleeve should be a loose fit on the conductors.

Wipe the last 2 inches of the conductors thoroughly clean, and file the ends up square.

Butt the conductors within the sleeve.

Apply heat on both sides of the orifice by means of two blow-lamps (*see* Pl. **81**, Fig. 1) and *at the same time* press the conductors together.

Continue the heating and pressing together of the conductors until molten metal is squeezed out of the orifice.

Remove the blow-lamps *as soon as* molten metal appears in the orifice.

The copper sleeve need not be removed, nor should the metal which has been squeezed out through the orifice be cut off.

Care should be taken that exactly the right amount of heat is applied ; if too much the metal will be burnt, whereas too little will mean an indifferent weld.

It is desirable to have a wind shield, lined with asbestos, to act as a conserver of heat when the joint is made at the top of a pole.

7. A *clamped joint* is necessarily inferior to a welded joint, owing to the oxidation of the aluminium, but with cables of over 0·2 sq. in. in cross-section welding is difficult and uncertain. Consequently, clamps must be made use of, unless the materials and tools for making the torsion sleeve joint (*see* para. 8) are available.

A large variety of clamps have been devised, and some examples are shown on Pl. **80.** Whatever form of clamp is used, however, it is essential that the aluminium of which it is made should be pure and unalloyed. It is far better to use a rough-looking casting than to encourage an alloy for the sake of appearance.

With the largest cables it may be found that aluminium clamps are not of sufficient strength. In such cases copper clamps must be employed, but care should be taken that such clamps are frequently inspected and cleaned.

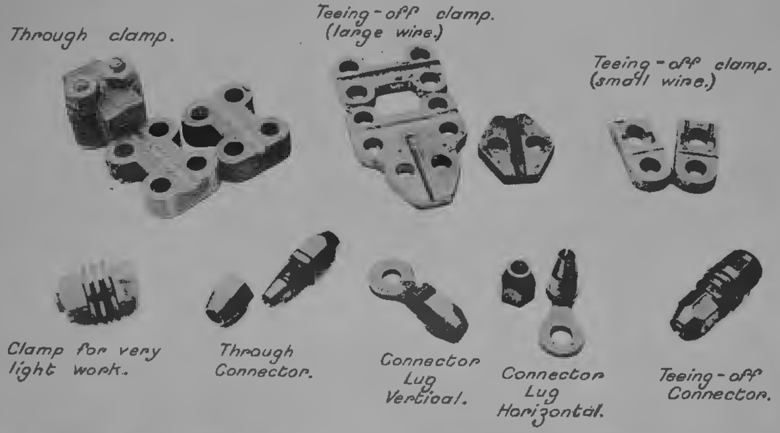
When more than one securing bolt is provided, the clamp should be pulled up by means of a steel bolt, and the aluminium bolts inserted one by one when the clamp is under compression.

After fixing, clamps should be painted over with a waterproof paint, and the painting extended along the conductors to a distance of at least 9 inches on either side. It is advisable to remove and clean all clamps every three years.

8. Aluminium cables, of all sizes up to 1 inch in diameter, can alternatively be jointed by means of the *torsion sleeve joint* (Pl. **81**, Figs. **2** and **3**). The two cable ends are slipped from opposite ends into an 8-shaped aluminium tube (Pl. **81**, Fig. **2**), so that they lie parallel within it. The tube is then gripped at each end by a special form of twisting clamp, by means of which it is given 2½ or 3½ complete turns, the half-turn being necessary in order that the two parts of the cable after twisting shall be in the same straight line. This makes a very sound joint, and it also has the merit of being able to withstand as great a strain as the cable itself.

9. **Binding-in** is another very important part of line construction, and needs careful attention. The utilizing of either the top or side groove of the insulator has already been explained (Sec. **50**) ; but it also should be noted that the use of the top groove, in spite of its obvious advantages, is liable, if badly designed, to lead to chafing of the cable or wire on the edges of the groove. This may, however, be obviated, to a certain extent and for a limited period of time, by first serving the cable or wire with binding wire as described below.

TYPES OF CLAMPS AND CONNECTORS.



JOINTING OVERHEAD CABLES.

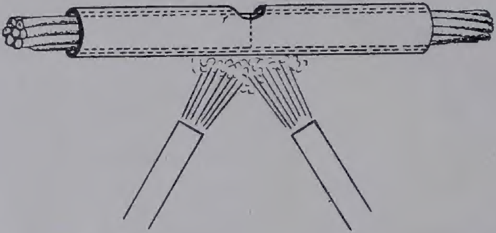


Fig. 1. Welding bare aluminium.

Fig. 2. Sleeve for torsion joint.

Fig. 3. Torsion sleeve joint. (aluminium.)

The *precautions* to be taken when binding-in are as follows :—

- i. Cut off the correct lengths of binding wire (to be ascertained by trial) before ascending the pole.
- ii. Avoid bending the line wire by straining too hard on the binding wire.
- iii. Do not use pliers except for cutting off the spare ends.
- iv. Avoid nicking either the line wire or the binding wire.
- v. Use soft binding wire *of the same metal as the line wire*, 14 S.W.G. for sizes up to 0·05 sq. in. and 12 S.W.G. for larger sizes of conductor.

10. *When binding-in on the side groove* proceed as follows :—

Take a suitable length of binding wire (about 9 ft. is required for a 0·193-in. conductor.

Starting with the middle point of the binding wire at point M in Fig. 1, Pl. **82**, serve the line wire for a length equal to the diameter of the neck of the insulator.

Take the end which leads from the top of the line wire (A), pass it round the neck of the insulator and take a round turn, from above downwards, round the line wire.

Take the other end (B), pass it round the neck of the insulator and take a round turn, from below upwards, round the line wire.

Pass both ends round the neck of the insulator again, and finish off by serving about 2 inches on either side of the insulator, end A winding from below upwards and end B from above downwards.

If these instructions are carefully followed, the turns of wire round the neck of the insulator will not ride upon one another.

When binding-in on the top groove proceed as follows :—

About 8½ feet of 14 S.W.G. will be required for 0·193-in. conductor.

Divide the binding wire into two equal parts and lay up together to form a double wire, leaving several inches of single wire at each end (8 in. in case of 0·193 conductor).

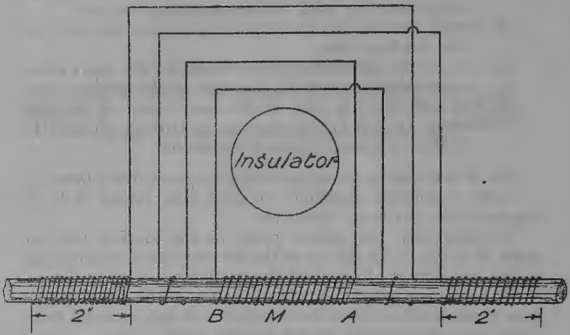
Starting with the middle of the double binding wire at point P (Pl. **82**, Fig. 2), serve the conductor for a distance equal to length of groove plus half an inch (*i.e.*, plus ¼ inch at each end).

Twist the double wire together at each end until the bottoms of the twists reach the neck of the insulator, and then pass one wire of each pair in a clockwise direction round the neck, and the other in a counter-clockwise direction.

Twist the pairs together again where they meet, until on bending upwards the tops of the twists just reach the conductor. (These two wires must go round the conductor in the same direction.)

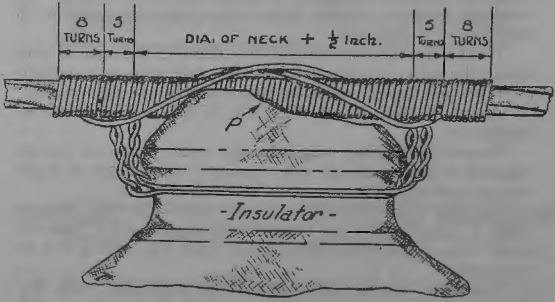
PLATE 82.

BINDING-IN.



Binding (Side Groove.)

Fig. 1.



Binding. (Top Groove.)

Fig 2.

Now take five turns round the conductor with the short wire of each pair.

Finally, take the other wire of each pair, pass them over the top of the insulator so that they cross each other and the conductor, and finish off with eight turns round the conductor.

11. **Terminating.**—Besides the making-off of an overhead conductor where it is led into a building or joined to an underground cable and at each side of a joint, it is advisable to terminate cables or wires at each side of a crossing.

Small wires up to 0·025 sq. in. in cross-section, such as are used for services, can be terminated by a method similar to that employed by the G.P.O. for iron and copper wires. The end of the line wire is taken round the insulator, and bent back along the standing part for about 3 inches; the two parallel parts are then bound with binding wire, leaving a *tail* of about 4 or 5 inches. This tail is bent round away from the standing part, so that connection may easily be made to the leading-in cable or wire.

For heavier wires and cables, clamps must be employed. Examples of such terminating clamps in actual use are shown on Pl. **90.**

12. Terminations can be supported by one of the following methods, viz. :—

i. *Double-groove pin-type insulators on straight pins.*—For double terminations for straight-through joints on light wires up to 0·05 sq. in. in cross-section, and for the single termination of light wires up to 0·025 sq. in. in cross-section, when teed off a larger wire.

ii. *Single-groove pin-type insulators on single J pins.*—For single terminations on light wires, up to 0·025 sq. in. in cross-section.

iii. *Single-groove pin-type insulators on double J pins.*—For double terminations on all cables and wires up to 0·05 sq. in. in cross-section, though method (i) (for small wires) and method (iv) (for large wires) are preferable.

iv. *Tensioning insulators.*—For single and double terminations of wires and cables over 0·05 sq. in. in cross-section, and for branchings of wires and cables over 0·025 sq. in. in cross-section.

When a double termination is made by either method (iii) or method (iv) it is advisable to fix a pin-type insulator on top of the arm to support the loop containing the joint, so as to prevent it making accidental contact.

55. *Branching and leading-in.*

1. Branching.—At those points in a distributing network where a number of circuits branch off, such as at feeding points, some convenient means of disconnecting the different distributors should be provided to facilitate the localization of faults. Generally speaking, if each incoming wire is terminated on a separate insulator, strap wires and mechanical connectors are sufficient for the purpose.

Open type isolating switches are sometimes installed as shown on Pls. **83** and **84**, but the expense is seldom justified.

If isolating switches or switch fuses are considered necessary they should be of the waterproof ironclad type as shown in Pl. **85**, or preferably they should be located in boxes fitted on the poles in an easily accessible position.

It must be emphasized that the indiscriminate use of fuses on an overhead system is objectionable and troublesome.

If a closed ring distributor is fed by several feeders, fuses will be necessary at certain points on the distributors to prevent a faulty section from putting the whole area out of action, but in overhead distribution work it is better for each feeder to supply a separate isolated area. Cases will occur where the distributors from one area meet those from another on the same pole, and although advantage may be taken of this in emergencies, it is advisable that they should not normally be connected together.

2. Leading-in.—It must be emphasized that to comply with the E.C. Regulations **all conductors must be insulated within 6 feet of a building**, to avoid danger to workmen. Neglect to comply with this regulation has recently led to several fatalities. T.R.S. cable or weather-proof cable of the " P.B.J. " type (*see* Post Office Regulations, T.E. 80, for Specification), satisfy the requirements for leading-in purposes, but ordinary V.I.R. insulated cable does not.

It must also be borne in mind that the connection between the overhead line and the main switch is not separately fused, and it therefore requires special attention.

When a service is to be led into a building, it is terminated on brackets on the face of the building (*see* Pl. **86**), *or* on a special hut fitment (*see* Pl. **87**), *or* on a pole adjacent to the building (*see* Pl. **62**), and the insulated leading-in wires are connected, by means of clamps or a simple bind, to the line wire or the tail of the termination.

The conductor of the leading-in wire should be of the same material as the line wire, to obviate electrolytic action, and a clamp connection (*see* Pl. **87**) is preferable to a simple bind (*see* Pl. **62**), owing to the greater likelihood of a comparatively high resistance in the latter.

FEEDING-POINT ON A D.C. 3-WIRE SYSTEM

PLATE 84.

FEEDING-POINT ON A 3-PHASE 4-WIRE SYSTEM.

[*To follow plate* 84.

H POLE. DISTRIBUTOR ISOLATING POINT.

LEADING-IN A 2-WIRE SERVICE.

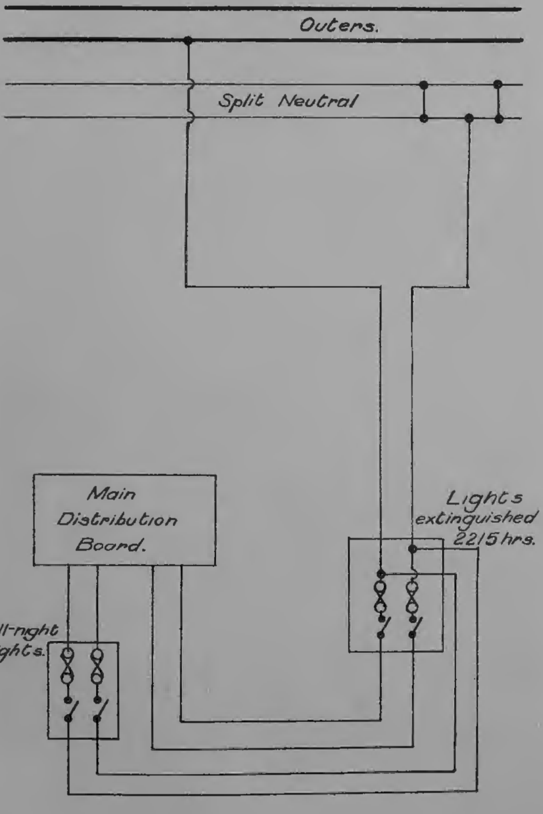
LEADING-IN TO HUT.

PLATE 88.

LEADING-IN TO BARRACK BLOCK.

LEADING-IN TO BARRACK BLOCK.

Diagram of Connections.



LEADING-IN D.C. 3-WIRE FEEDERS.

FOUR-POLE TERMINAL STRUCTURE.

(3-Wire D.C. Distribution.)

FOUR-POLE TERMINAL STRUCTURE.

(3-phase A.C. Distribution.)

T.R.S. cables should then be led in through galvanized conduit, shaped so as to prevent the ingress or settlement of water.

With this object in view the conduit or pipe should always be bent over, so that the leading-in wires enter upwards, and it is inadvisable to use a long length of conduit without making provision for the draining-off of condensed moisture.

The conduit should extend down to the D.B. or main switch fuse, to ensure that this main connection is as robust as possible, and to render it more difficult to make unauthorized connections on the " live " side of the switch. This is of particular importance where meters are installed.

Where trouble is experienced owing to condensation, particularly in damp tropical climates, *single*-core T.R.S. cable cleated to the walls may be considered satisfactory if care is taken to select a position where accidental damage or unauthorized interference is unlikely. Where the cables pass through the walls, the holes should be bushed with porcelain tubes, one for each cable.

Where it is impracticable to lead in as above, the distances are short, and there is no traffic, ordinary V.I.R. lead-covered cable or T.R.S. cable buried direct in the ground and protected by creosoted pick boards have been found satisfactory. Neither plain V.I.R. nor T.R.S. should be drawn into conduit or iron pipe in the ground, as dampness sets up action between iron and the rubber sheathing, and the latter soon rots away.

Where the leading-in wires feed a switch-fuse or other box on the outside of the building, it is recommended either (*a*) that the conduit should be bent so as to *lead-in at the bottom* of the box, and a drain hole provided at the lowest point of the conduit, or (*b*) that the leading-in wires be brought down the face of the wall on bobbin insulators or cleats, and made to enter the box from the bottom. Thus the troubles due to condensation will either be mitigated or avoided. The methods of leading-in shown on Pls. **87** and **88** were employed at Tidworth and Bulford, respectively, and gave a good deal of trouble.

Pl. **88** shows an instance of the leading-in wires for a barrack block being made off on the distributor itself, the latter being run on brackets on the buildings. It is of further interest in that it shows one main D.P. switch fuse controlling the lights extinguished at 10.15 p.m., and another controlling the all-night lights. A diagram of the connections is given on Pl. **89.**

3. The leading-in of the feeders to the generating or transformer station is a matter requiring special consideration, and the method to be employed must vary with circumstances.

Pls. **90** and **91** show the lead-in of five 3-wire feeders (one with the outers each consisting of 2 cables, owing to the large section of conductor required) and one 3-wire distributor to Tidworth generating station. The cables are all terminated by means of clamps on shackle insulators, and the leading-in cables pass over the top of pin-type insulators to choking coils. The inner ends of the choking coils are connected to cables which pass through porcelain insulators in the wall. On the line side of the choking coils Garton-Daniels arrestors are connected in leak to earth.

Pl. **92** indicates to a certain extent how the leading-in to the transformer station at Bulford is carried out.

56. *Safety precautions.*

1. In the neighbourhood of roads, railways, and signal lines, certain modifications are necessary in overhead power line construction to minimize danger to individuals. The legal regulations on the subject are those prescribed by the Electricity Commissioners (El.C. 53) and by the Postmaster-General (E. in C. 231 for H.V. lines and T.E. 80 for M.V. lines).

Prior to 1923 the most favoured method of guarding was the erection of an earthed cradle, such as that shown on Pl. **93.** These cradles do certainly afford complete protection under normal circumstances and so long as the weather is not too severe, but they are unsightly and costly, and, on account of the additional wind-pressure loading, require very much stronger poles. Moreover, they are troublesome to erect, and more than likely, in exposed situations, to collect such heavy ice-loads as to cause breakdowns. The true value of cradles is, therefore, questionable, and they have come to be regarded as unsatisfactory means of protection.

Disconnecting devices, designed so that the conductor is switched off from the supply as soon as a break occurs, and schemes for earthing broken conductors before they can reach the ground, have been tried, but neither method has proved altogether satisfactory in practice.

Particular attention is drawn to the following points in the E.C. Regulations :—

Smallest conductor.—The minimum size permitted is 0·0201 sq. in. (8 S.W.G.) for line conductors, and 0·0129 sq. in. (10 S.W.G.) for service lines.

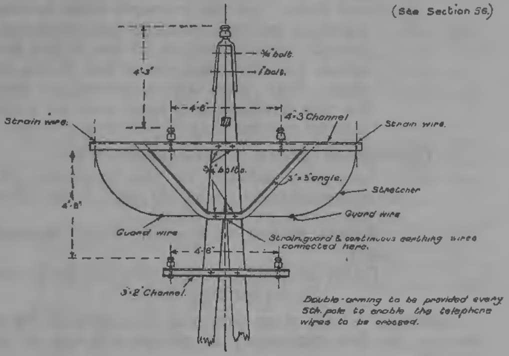
2. **Precaution against leakage.**—

(i) *H.V. lines* (above 650 volts D.C. and 325 volts A.C.) All the pole ironwork must be bonded together and connected to earth, either by (*a*) an earth plate at every pole, or (*b*) a continuous wire earthed four times per mile.

Plate 93.

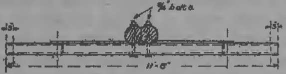
DETAILS OF CRADLE CONSTRUCTION.

(See Section 56.)

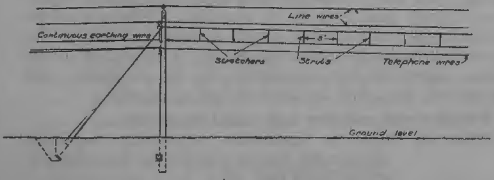


Double-arming to be provided every 5th pole to enable the telephone wires to be crossed.

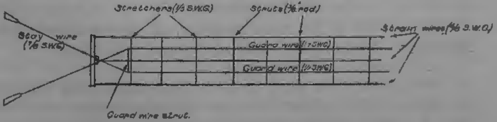
ELEVATION OF POLE.



PLAN OF CHANNEL ARM.



ELEVATION OF CRADLE AND LINE.



Plan of Cradle.
(Line and Telephone Wires not shown.)

(ii) *L.V. and M.V. lines.*

(*a*) Metal Poles. A continuous earthed wire connected to all the poles.

(*b*) Wood Poles. All the ironwork must be bonded together, but the bonding wire must not be brought down to within 10 feet of the ground unless insulated and connected to an earth plate. Stay wires are considered as part of the pole ironwork and must have an insulator inserted not less than 10 feet from ground.

3. Precautions against broken conductors.—

H.V. lines.—In addition to the increased ground clearance referred to in Sec. **51**, para. 4, the following modifications are prescribed :—

Within 50 feet of a public road, railway or canal.

Either (*a*) Duplicate insulation and strap wire, or
(*b*) An earthing device.

Reference (*a*) the strap wire may be copper of the same size as the line conductor, or phosphor-bronze of equal strength.

Reference (*b*) this usually consists of an earthed bar or bow, preferably of copper, affixed to the pole and so arranged as to intercept and earth a falling conductor before its end reaches the ground. Earthing bows are shown in Pl. **69,** about 7 inches below the conductors and projecting about 12 inches from the insulator. The clearances in this example are on the small side, and would have to be increased at higher voltages if bird trouble is to be avoided. Where a single earth bar is used of sufficient length to intercept any of the three conductors in triangular formation, it should be about 16 inches below the two conductors on the cross-arm, and should project from pole, as nearly 3 feet as possible.

4. Public road, railway and canal crossings.

Either (*a*) Duplicate insulators supporting duplicate conductors, bound together at intervals not exceeding 5 feet, or
(*b*) Duplicate insulators and strap wires plus an earthing device.

Method (*b*) is the more popular, as (*a*) requires tensioning insulators, larger poles, and additional line stays.

L.V. lines.—All situations.

If the wires are fixed in a vertical plane with the earthed neutral at the bottom, no special guard wires are required (*see* Pl. **69**). With other arrangements of conductors the neutral must be so disposed as to intercept and earth a falling conductor. This requirement was originally met by using a split neutral as shown in Pls. **62, 63,** &c., but a single neutral conductor now suffices if the same length of cross-arm is used and the neutral conductor is staggered from side to side at succeeding poles.

Railway crossings.—The E.C. Regulations (*a*) for crossings (*i.e.* duplicate conductors on duplicate insulators) must be complied with, and in addition, the Railway Authorities generally require that the crossing should be at right angles to the rails and as short as possible.

5. **Telegraph and telephone crossings.** — Full particulars of the P.O. requirements are given in the Engineering Department's memoranda referred to in para. 1, but the local P.O. Engineer should always be consulted as to details.

H.V. lines.—The P.O. prefer a cable crossing, but permit an overhead crossing if the line has double conductors on double insulators, and in addition a cradle is erected on separate supports. One form of cradle construction is shown in Pls. **75** and **93.**

L.V. lines.—Crossings should be as nearly as possible at right angles, as the requirements are then simpler.

If the power wires are in the same vertical plane, and the signal wires are above, a single earthed wire above the power wires satisfies the requirements. If the signal wires are below, independent guard wires may be used, but it is generally better to split the neutral at the crossing and cross lace every 6 feet as specified. The normal clearance between guard wires and signal wires is 4 feet, but 2 feet is permitted in special cases.

No guard wires are required if the power conductors are insulated and supported on an earthed steel wire, neither are they required up to 250 volts if either the signal wires or the power conductors are insulated with an approved weatherproof covering.

57. *Miscellaneous details.*

1. **Protection from lightning, &c.**—The problem of guarding against the effect of abnormal electric conditions, whether due to atmospheric disturbances or to internal causes, such as resonance, switching, &c., has already been fully discussed in Sec. **25**, and little more remains to be said. The section quoted deals mainly with H.V. transmission lines, but the simple requirements of L.V. networks are given in para. 16.

It is not considered necessary to provide any special form of protection where house services enter buildings ; the main fuses provide a sufficient safeguard.

2. Street lighting.—Where the streets of an overhead distribution area have to be lighted, it will usually be found convenient to do so by means of bracket lights on the poles themselves. Each light can, of course, be provided with its own switch, but it will in all probability prove more economical to run an extra wire as a switch wire, so that all lights can be controlled from a central position. The connections to the switch wire and outer, or phase, will be made by clamps or simple binds in the ordinary way (*see* Sec. **55**), and the insulated wires led down the pole on button insulators or cleats. Examples of street lighting brackets are shown on Pls. **67** and **68.**

Where it is desired to reduce the illumination of the streets for the purposes of economy, say at midnight, it will be necessary to run two switch wires, one controlling the *all-night* lights and the other the *midnight* lights.

Further details concerning exterior lighting are given in Chap. X.

3. Telephone wires on power lines.—Intercommunication between a station and sub-station is usually imperative, and if no telephone system exists, it is sometimes the practice to run the telephone circuit on the power line poles. There is no objection to this providing certain precautions are taken.

In the first place, the telephone wires should be placed *below* the power lines, as, being smaller wires, they are more liable to mechanical failure. Secondly, the telephone wires should be at least 5 feet from the power lines, and a high degree of insulation is necessary on account of the high voltages induced by electro-static induction, *e.g.*, suitable telephone insulators for a line voltage of 11**kV** should have a 3**kV** rating. (The B.S. specification recommends that the telephone insulators should be identical with the line-wire insulators.) Thirdly, the telephone wires should be revolved to eliminate the effects of electro-magnetic induction. Fourthly, when the 3-phase system has no earthed neutral point, a drainage coil, consisting of a split choking coil with its central point connected to earth and suitably protected by gaps, should be provided on the telephone circuit. Finally, the telephone instruments themselves must be provided with arrestors.

A suspended lead-covered twin telephone cable is better than the open wires referred to above, but is more costly.

Ordinary telephone circuits, other than the intercommunication line mentioned above, should not be attached to power poles, whether H.V. or L.V. This should be taken as a rigid rule under peace-time conditions, but it should be understood that from an active service point of view such a reservation is quite unnecessary. During the Great War H.V. poles were used extensively by the Signal Service for telephone wires, without any inconvenience or accidents to personnel or apparatus, and a great economy in the expenditure of poles and labour was effected thereby. Immunity from induction was largely due to the fact that the lightly-insulated telephone wires were run on porcelain bobbins, so that the two wires of a pair were only about 1 inch apart. A spacing of 6 feet below the H.V. wires was aimed at, but frequently the telephone wires were only 3 feet below the power lines, and no special arrestors were used on the telephone circuits. On heavy telephone routes multicore lead-covered telephone cable was suspended in the usual way on H.V. poles without any disaster.

4. **Junction of overhead lines with underground cable.**—The terminal points of H.V. lines, up to 30**kV**, are usually connected to paper-insulated underground cable, and the junctions are effected by means of terminating boxes (outdoor type) fixed on the poles. The cable is led through a gland at the bottom of the box, and the connections from the line wires are led through porcelain insulators. When the joints have been made, the boxes are filled with compound and sealed. Terminating boxes *in situ* on the terminal poles are shown on Pls. **75** and **76.**

For terminating a 3-phase cable inside the station or substation the indoor type of terminating box is used.

5. **Maintenance** of overhead lines need not be a serious item if due care is taken in design and erection, and if periodical patrolling is done. The latter will often serve to disclose an incipient fault before it has time to develop. Important main lines should be *walked through* once a week at least, and much can be done by the cultivation of a keen interest in the welfare of a system on the part of all connected with its working.

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Overhead Transmission Lines and Distributing Circuits. Kapper. 15*s*.

Overhead Power Lines. Capt. W. M. N. Morecombe, R.E. 15*s*.

The Construction of Aerial Lines on Roads and Railways. Post Office Technical Instructions XIII. 1*s*. 6*d*.

British Standard Specifications :—

125. Hard Drawn Copper Conductors. 2*s*.
134. Steel Poles. 10*s*. 6*d*.
137. Porcelain Insulators. 2*s*.

British Standard Specifications—*continued*

139. Red Fir Wood Poles. 2*s.*
215. Hard Drawn Aluminium and Aluminium Steel Conductors. 2*s.*

D. W. Standard Specifications for E. & M. Services :—

1. H.V. and E.H.V. Overhead Lines.
2. M.V. and L.V. Overhead Lines.

Post Office Engineering Departments Regulations, E. in C. 231 (H.V. Lines).

Post Office Engineering Departments Regulations, T.E. 80 (L.V. and M.V. Lines).

PART II.—UTILIZATION OF ELECTRIC LIGHT AND POWER.

CHAPTER VII.

INTERIOR ILLUMINATION.

58. *General considerations.*

1. It is only in comparatively recent years that the problems of interior illumination have received the attention they deserve, and even now the advantages and benefits of efficient lighting are not generally realized. During the early years of electric lighting, there was a general tendency to imitate exactly the methods employed in gas lighting, designers neglecting the great increase of flexibility afforded by electricity. In later years the methods adopted went to the other extreme; lamps were put exactly where they were obviously wanted and nowhere else, and no attention was paid to the general lighting of the room, with the result that the illumination was anything but uniform and there were excessive contrasts.

A mean between these two extremes should be the aim of the illuminating engineer, and it will be found that if the general rules given in the next paragraph are adhered to, good results will be obtained.

2. General rules for good lighting.

i. All calculations and design are primarily based on a sufficient illumination on the working plane. This plane varies with the place under consideration, *e.g.*, in a foundry it is the floor, in an art gallery the walls. In most cases it is taken as a plane 3 feet above the floor. The point will be dealt with in greater detail in Sec. **59**, but it may be mentioned here that an illumination of 2 to 3 foot-candles is generally recognized as being sufficient for reading and writing.

ii. The illumination should not be judged by the brightness of the lamps. This is a common error. If the light source strikes the eye at once and looks brilliant it does not necessarily mean that the illumination on the working plane is good; it probably means that the lights have been wrongly sited or that the wrong type of equipment is being used.

iii. If possible, light sources should be outside the normal direct vision. This can be attained either by placing the lamps at a sufficient height or by shading them from the eyes of the occupants. In normal circumstances the eyes should not encounter surfaces where the brightness exceeds 10 candle-power per square inch. The brightness of a metal filament is about 1,000 candle-power per square inch.

iv. Select the lighting equipment with care and with due regard for the purpose for which it is required. This has an important bearing upon the annual cost of the installation ; if diffusing globes are used when concentrating reflectors are indicated it will be obvious that lamps of a greater wattage are required.

v. *Avoid excessive contrasts.*—If a high degree of illumination is necessary at a particular place for a certain purpose, such as fine drawing, the remainder of the room should not be in darkness. If such were the case the eyes would be severely strained each time they were raised from the drawing-paper, owing to the fact that the process of adaptation takes time.

vi. *Site the lamps and switches with great care.*—In many cases the best position for a lamp will be obvious, but there are occasions when a matter of inches will make a considerable difference in the avoidance of undesirable shadows. Similarly, thoughtful selection of the switching positions will add to the comfort and convenience of the occupants and may lead to economy in current consumption.

vii. *Keep lamps and shades clean.*—This is a much more important factor than is generally realized. Dirty bulbs and reflectors may mean a loss of as much as 25 per cent. of the light, or even 40 per cent. in extreme cases, and in bad situations where the fittings are difficult to get at and clean, a depreciation factor must be allowed for in the design (*see* Sec. **61**).

viii. *Maintain the supply at the intended voltage.*—This scarcely comes within the scope of this chapter, but it is a point which is frequently overlooked, especially in the case of large additions or extensions to an existing system. The effect of voltage variation on the candle-power of a lamp is dealt with in Sec. **65** ; from that it can be readily seen that a variation from the declared voltage of more than the 4 per cent. permitted will play havoc with the available illumination.

3. Barrack Synopsis scales of lighting (*see* Appendix V). —In the lighting of barrack buildings the engineer officer must be guided by the scales of illumination given in the Barrack Synopsis ; it should be noted, however, that these scales are intended as a guide only, and that rigid adherence to them under all circumstances is not absolutely essential, though material departure from them would have to be specially authorized.

The Barrack Synopsis scales are given in terms of watts and feet super, *i.e.*, one watt is allowed to a stipulated number of square feet of floor space, according to the class of building. This method, while simplifying matters and giving fair results where buildings of a uniform type are concerned, has many drawbacks; such factors as voltage of supply, height and shape of rooms, colour and condition of walls, ceilings, &c., are ignored, and these are factors which exercise a considerable effect on the illumination. Nevertheless, an intelligent application of the Barrack Synopsis scales is all that is required for ordinary purposes.

4. In planning an illumination scheme the various points to be considered are as follows :—

i. The intensity of illumination required on the working plane.
ii. The type of equipment to be employed.
iii. The gross amount of light necessary to give the required intensity of illumination.
iv. The size and location of the light units.
v. The location of the switches.

Each of these will be considered in detail in the following paragraphs, though it must be recognized that they are all interconnected.

For Barracks, a Schedule of Authorized Electric Light Fittings is given in the Appendix to D.W. Standard Specification for E. and M. Services No. 12.

59. *Photometry.*

1. The principal photometric definitions used in electric lighting are given in the Illumination Research Technical Paper No. 1 of the department of Scientific and Industrial Research, to which the reader is referred for further details.

2. The unit of illumination is the **foot-candle,** which is the illumination from a source of 1 candle-power received normally at a point on a surface at a distance of 1 foot, and there are two fundamental laws of illumination, viz. :—

i. **The law of inverse squares,** which states that the intensity of illumination on a surface normal to the light rays is inversely proportional to the square of its distance from the source. Thus a source of 16 candle-power will give an illumination of 16 foot-candles at 1 foot distance, whilst at 2 and 4 feet the illumination will be 4 foot-candles and 1 foot-candle respectively.

This law, which concerns direct lighting (*see* Sec. **60**, para. 2) only, is not strictly true unless the light source is a point, but the errors when the source is a filament lamp or a disc are so small as to be, for all practical purposes, negligible.

ii. **The Cosine Law,** which states that the intensity of illumination on a surface which is not normal to the light rays is proportional to the cosine of the angle of incidence (*i.e.*, the angle which the incident ray makes with the normal to the surface). Thus, in Fig. 52, if the light source, S, be 16 candle-power the intensity of illumination at the point P on the surface AB will be $\frac{16}{4^2} \cos 60°$, *i.e.*, 0·6 foot-candle.

These two laws determine only the **intensity of illumination.** The actual brightness of the surface will depend also upon its reflecting power.

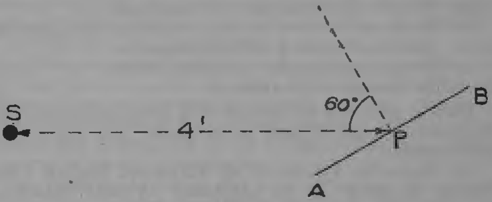


Fig. 52.

3. The most suitable intensity will depend upon the purpose for which the illumination is required. Thus, as has been stated in Sec. **58**, para. 2, the intensity of illumination required for reading and writing is from 2 to 3 foot-candles: in a passage, where it is only necessary for people to see their way, 0·25 to 0·5 foot-candles is ample: a billiard-table needs an intensity of at least 15 foot-candles: in a factory from 1·5 to 10 foot-candles may be wanted, according to the class of work performed.

4. Suggested average values of illumination intensity for various buildings not mentioned in the Barrack Synopsis are given in Table **I**, these values being for direct lighting. They are considerably higher than those generally adopted a few years ago, but some authorities at the present time advocate even higher values. Moreover, it must be remembered that the installation of a certain amount of light does not necessarily mean that that amount will be always in use; suitable switching arrangements (*see* Sec. **75**) and location of individual lamps in places where special illumination is required, *e.g.*, writing tables (*see* Sec. **62**), will enable undue waste of energy to be avoided.

TABLE I.—*Average values of illumination intensity for various buildings.*

	Foot-candles
Ball-room	3
Billiard-room (general lighting)	1
Billiard-table	15
Carpenter's shop	2 to 3
Church	2
Corridors	0·3 to 0·5
Courts, racquet	12
,, squash racquet	6
,, tennis	6
Drawing office	6 to 8
Engraving	10 to 12
Factory (with local lighting)	0·5
,, (without local lighting)	1·5 to 3
Foundry	2 to 3
Garage	2
Hospitals, corridors	0·5
,, operating table	12
,, wards (with no local illumination)	1·5
,, ,, (with local illumination)	0·5
Laboratory	2 to 4
Laundry, general illumination	0·5 to 1
,, ironing table	4
Library and reading room (exclusive of local lights)	1
Machine shop, general lighting	1 to 2
,, ,, local lighting	2 to 5
Paint Shop	2
Pattern shop	2 to 4
Power house	2
Residences, bedrooms (dressing-table)	4
,, ,, (general)	0·5 to 1
,, dining-room (dining-table)	4
,, ,, (general)	1
,, drawing-room (exclusive of local lights)	1·5
,, hall	1
,, kitchen	2
,, porch	0·5
,, schoolroom	2
,, sewing (light goods)	3 to 4
,, ,, (dark goods)	6 to 8
Stores	0·5 to 1
Studio	4

5. *Polar distribution curves.*—The candle-power emitted by a lamp or complete fitting will not in general be the same in every direction, and if any plane be considered and photometer readings be taken while the photometer is moved round the lamp in this plane a curve may be drawn of the candle-power in different directions. This is known as a polar distribution curve, and examples in a vertical plane (the most usual) are given on Pl. **94**.

60. *Types of lighting equipment.*

1. The next step is the selection of the *method of lighting, i.e.*, direct, indirect, or semi-indirect, and the *type of shade or reflector* that will be best suited to the installation.

This question is so intimately connected with that of the size and location of the light units (*see* Sec. **62**) that it is not possible in practice to consider one without the other; it is, however, necessary to explain separately what results are to be expected from these three methods of lighting, and also to discuss briefly those highly important features, reflectors and shades.

Proper distribution of the light in a room is essential. In the majority of cases a good general illumination is to be aimed at, which means uniformity and the avoidance of contrasts. A room in which the illumination is dim but uniform will really be better lighted than one in which the light is brighter but unevenly distributed.

Provided that the various parts of any visual picture remain of the same relative brightness, very considerable variations may be made in absolute brightness without seriously affecting the distinctness of detail. With well-distributed light, such as daylight, this fact is clear; it is equally as easy to read at sunset as at midday, although the brilliancy of the sun at sunset may only be about $\frac{1}{300}$ of its brilliancy at noon.

The fundamental point to remember is that sufficient and sufficiently uniform illumination is required on a certain working or reading plane. As has been stated in Sec. **58**, para. 2, the mere fact that the luminous source looks brilliant is no guarantee that the equipment is satisfactory; indeed, it is much more likely that something is wrong.

2. **Direct lighting** includes all those forms of lighting in which the light rays come direct from the light source, or from a globe or reflector surrounding or partly surrounding the light source, to the working plane or object which is to be illuminated. It is the simplest form of lighting, and is undoubtedly cheaper than semi-indirect lighting, both as regards installation costs and annual cost of energy.

3. In the early days of electric lighting scientific principles had not been applied to the designs of reflectors and shades, and the fittings used were frequently very unsuited to their purpose. The choice of reflectors and shades—and there is no clear distinction between the two, since a shade usually acts, usefully or otherwise, as a reflector, and a reflector always shades the light source from certain points—is of great importance. But only a limited number of shades are

included in W.D. contracts, and for this reason it frequently happens that too little attention is paid to the matter of shading. The plain opal or enamelled iron shades are quite suitable for the general and local lighting of a large number of the rooms in military barracks and workshops: there are, however, many cases where something more elaborate is desirable. It is not feasible to contract for shades to meet every contingency; consequently such cases must be met by selection from manufacturers' catalogues.

Naked filaments must not be within the range of vision, which may be taken as extending at an angle of 20° above the horizontal from the observer's eye. Lamps with clear bulbs should not be used unless they are enclosed in a bowl or globe of frosted or opal glass. Lamps with internally frosted bulbs are now standard up to 100W (*see* Sec. **65**).

When selecting shades for a particular purpose, care should be taken to ensure that they are suitable for the size and type of lamp to be employed, and the polar distribution curve should be studied. The ordinary ornamental glass shades are of little use; they do not direct the light effectively where it is wanted, and merely absorb a great deal of it. Similarly, silk shades, although useful in some cases for softening the light and for decorative purposes, have little directive effect and absorb a lot of light. Although an infinite variety of scientifically-designed reflectors exist, the majority can be classified under the following headings:—

i. *Extensive*, which direct a considerable portion of the light to the upper region of the lower hemisphere and give a maximum intensity at about 45° below the horizontal.

ii. *Intensive*, which give a moderately even distribution over the whole of the lower hemisphere. (The British Standard industrial reflector described in B.S.S. 232 of 1926 comes in this category.)

iii. *Focusing*, or concentrating, which direct most of the light within an angle of 10° to 15° from the centre line.

Pl. **94** gives typical polar distribution curves for these three types.

The decision as to which type of reflector to employ calls for some judgment, and to ensure uniform illumination the ratio of spacing to height above the working plane must be carefully considered (*see* Sec. **62**).

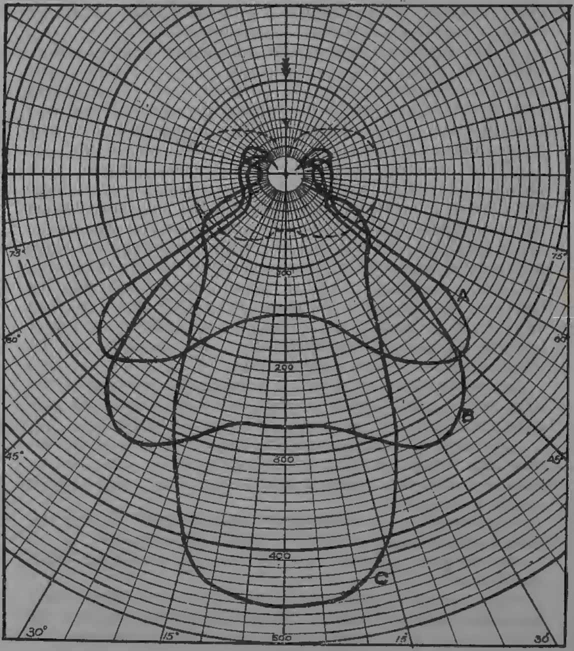
In this connection, B.S.S. No. 398, giving a "*Classification of Symmetrical Light Distribution from Lighting Fittings,*" has just been issued.

In this specification the term "*frame ratio*" is employed, *i.e.*, the ratio of the width (w) to the height (h) of a rectangle which just encloses the polar curve of the light distribution in the hemisphere containing the major portion of the total flux.

Plate 94.

CHARACTERISTIC DISTRIBUTION CURVES OF REFLECTORS.

With Gas-filled Lamp.



Dotted curve = Bare Gas-filled Lamp (maximum c.p. 100)
A ,, = ,, ,, ,, with Extensive Reflector
B ,, = ,, ,, ,, ,, Intensive Reflector
C ,, = ,, ,, ,, ,, Focusing Reflector

The "*frame ratio*" is then used to define the following types of fittings :—

Class.	Term.	Frame ratio limits.	The zone which includes direction of maximum luminous intensity.
I.	Extra narrow	below 0·18	0° to 5°
II.	Narrow	0·18 to 0·8	0° to 24°
III.	Intermediate	0·8 to 1·4	0° to 45°
IV.	Wide	1·4 to 3·0	0° to 90°
V.	Extra wide	above 3·0	48° to 90°

4. Globe fittings of translucent glassware may be employed with advantage when a good diffusion of the light is desired or when it is essential that the light source be completely hidden (*see* B.S.S. 324). It must, however, be remembered that the employment of any form of globe involves actual loss of light, the absorption by various kinds of glass being approximately as under :—

	Per cent.
Clear glass	5 to 12
Ground glass	20 to 30
Opaline glass	20 to 40
Heavy opalescent glass	30 to 60
Ruby glass	85 to 90
Cobalt blue glass	90 to 95

Good diffusion, by which is meant uniform brightness of the globe all over, cannot be obtained with clear glass nor even with ground glass, and in normal circumstances a good deal of light is wasted by being thrown upwards. The latter drawback can be combated to a certain extent by installing a directive reflector above the lamp or by employing prismatic glass, but prismatic glass globes cannot be constructed to give the same directive effect as prismatic glass reflectors.

It is very desirable that fittings should be well ventilated. Totally enclosed fittings may be preferable in many cases (*e.g.*, in the tropics, to prevent the entry of insects), but the life of the lamps used in such fittings will be less than the rated value.

5. **Indirect lighting** includes those forms of lighting wherein all the useful rays of light are obtained by reflection from the ceiling and walls, the light sources themselves being completely hidden within opaque bowls or in deep cornices near the ceiling. Such forms of lighting must naturally

lead to loss of light in reflection; also the fact that the working plane is not the most brilliantly illuminated portion of the room gives a false impression of the degree of illumination.

Indirect lighting is suitable for large reception rooms, &c., and for drawing offices, where practically shadowless illumination is desirable. The good diffusion obtainable from a white ceiling also enables the light to penetrate into remote corners of rooms, recesses, &c. Generally speaking, however, indirect lighting fittings are expensive and the lighting effect is somewhat flat and monotonous—even depressing —for ordinary interiors, and consequently semi-indirect lighting is preferable.

It might also be pointed out that indirect lighting depends for its success upon the condition and plainness of the ceiling, and that a general dinginess is much more harmful than in the case of direct lighting.

6. **Semi-indirect lighting** is a compromise between direct and indirect lighting, combining the advantages of both. In a well-designed semi-indirect installation, where glass or alabaster bowls, suspended in rings, are used, and whose internal surfaces reflect the major portion of the light upwards, an efficiency of from 40 to 45 per cent. may be secured. The best results are obtained with translucent glassware, transmitting from 15 to 20 per cent. of the light downwards and supported by fittings from 8 to 9 feet above the floor. The actual position of the lamp with reference to the bowl is also a matter of great importance from the point of view of appearance. If possible, the hard line of division between brightness and shadow should be so arranged as to coincide with cornice, picture rail, or some other well-marked feature; this consideration may make it necessary to modify the suggested height of 8 to 9 feet.

The great advantage of this system is that it removes the uncomfortable impression of "something missing" that is apt to be experienced when the source of light is completely concealed. The source of light is evident, but its surface brightness has been diminished to an agreeable value, and the advantage of widespread diffusion of light from the ceiling is still obtained. It is possible that, in living rooms, the resultant illumination may still be considered somewhat monotonous; where such is the case the installation of one or more local lights, as standard lamps, is recommended.

With this form of lighting there is danger of loss of efficiency due to the accumulation of dust in the bowl, and bowls should be cleaned very frequently.

In B.S.S. 398, referred to above, the following classes of lighting are now standardized :—

Class of Lighting.	*Definition* (percentages of total flux).
(*a*) Direct ..	90% or above in *lower* hemisphere.
(*b*) Semi-direct ..	60% to 90% in *lower* hemisphere.
(*c*) General ..	40% to 60% in *either* hemisphere.
(*d*) Semi-indirect	60% to 90% in *upper* hemisphere.
(*e*) Indirect ..	90% or above in *upper* hemisphere.

61. *Photometric calculations.*

1. The total candle-power that may be installed in the majority of barrack buildings is governed by the Barrack Synopsis scales (*see* App. V), and no further calculations will be necessary ; but for buildings and rooms which are not referred to in the Barrack Synopsis, or which are used for purposes other than those stipulated, and in cases where there is great divergence from the normal in the matter of colouring, decoration, height, shape, &c., some calculations will have to be made.

2. In the first place, the approximate nature of these calculations must be stressed. The value taken for the lumen emission of a lamp is only a nominal one (*e.g.*, a 230-volt 60-watt lamp is rated to emit 582 lumens, but may actually emit anything between 495 and 669 and still comply with the B.S.S.). Again the figure taken for utilization factor (para. 4) is one based on past experience, and the value actually obtained in the scheme under consideration may not be within 20 per cent. of that originally estimated. Luckily the human eye has a wide range of adaptability, and as a result an inability to differentiate between illumination intensities of, for example, 2½ and 3 foot-candles, and consequently meticulous calculations even where possible are unnecessary.

3. Light may be looked upon as a flow of a particular kind of energy outwards from any light-giving source, and the intensity of illumination of a surface will be proportional to the amount of this energy that strikes that surface.* This flow of energy cannot be measured directly, and the simplest method of determining it is to measure the illumination produced on a test surface and to define the unit rate of flow from the illumination it produces. The unit of light flux is the LUMEN ; when a surface of 1 square foot in area is

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* Only radiation to which the human eye is sensitive, *i.e.*, with wavelengths between 0·4 and 0·8 micron, can be considered in this connection.

uniformly illuminated to an intensity of 1 foot-candle the amount of incident light is 1 lumen.

If we had a light source of 1 candle-power in every direction, every point on a sphere of 1 foot radius round this source would by definition be illuminated to an intensity of 1 foot-candle. The surface area of this sphere is 4π square feet, and consequently the total light flux incident upon it is 4π lumens. In practice no light source is uniform in every direction, but we can determine the total light emission of a source from its polar distribution curve and compare it with that from this imaginary source, which, as we have seen, is 4π lumens. This unit source of light is a **mean spherical candle-power** abbreviated as m.s.c.p. A source giving 2,514 lumens is thus equivalent to $\frac{2{,}514}{4\pi}$ or 200 m.s.c.p. It will be appreciated that this is a much better measure of its value as an illuminant than its candle power in any one particular direction, which will vary with the type of source and the reflector used with it.

4. Lumens required. The net lumens required upon the working plane must first be obtained by multiplying the area of that plane (usually the same as the area of the room) in square feet by the intensity of illumination decided upon (*see* Sec. **59**) ; but to find the size and number of lamps to be installed allowance must be made for the waste of light by reflection and absorption at fittings, walls, ceilings, &c. This is done by dividing the net lumens by a *utilization factor* and multiplying by a *depreciation factor* if necessary to obtain the total lumens that the light sources have to emit.

The **Utilization Factor** is thus the ratio of the net lumens, *i.e.*, the light flux which reaches the working plane, whether direct or by reflection, to the gross lumens, *i.e.*, the whole flux of light emitted from the lamps. Strictly speaking, this factor should allow for all possible variations in rooms mentioned in the preceding paragraph ; the difference in reflective quality of various substances will be realized when it is stated that polished silver reflects 92 per cent. of the light it receives, whilst black velvet will reflect 0·4 per cent. only.

Elaborate tables of utilization factors for rooms of different sizes, shapes and heights, and with differently coloured walls and ceilings, may be found in the publications of the Electric Lamp Manufacturers' Association, but in most cases, for the reasons given in para. 2, the following general values will give sufficiently good results :—

Direct lighting	0·5
Semi-indirect lighting	0·4
Indirect lighting	0·3

The size of a room does not materially affect the result. In a small room the walls, if light-coloured, make a distinct contribution, whilst in a large room, provided with a number of lamps evenly spaced, the contribution from the walls at any particular point is small, but that point receives light from several lamps.

The depreciation factor to be allowed is a matter of individual judgment of the ease of cleaning and accessibility of the fittings and the likelihood of their receiving attention. In barracks 1·2 is a suitable figure to work to; 1·4 may have to be allowed in inaccessible and smoky places.

Then total lumens required

$$= \text{Area in sq. ft.} \times \text{illumination in ft. candles} \times \frac{\text{Depreciation Factor}}{\text{Utilization Factor}}$$

$$\text{and m.s.c.p. to install} = \frac{\text{Total Lumens}}{4\pi}$$

Suitable lamps can then be looked up in the D.W. Contract Circular or in B.S.S. 161.

It will be obvious that when installing semi-indirect lighting every endeavour should be made to include in the area reflecting the direct light as much light-coloured surface as possible. For example, in a room with a light frieze, the line of division (referred to in Sec. **60**, para. 6) should be made to coincide with the picture-rail rather than the cornice.

5. **Photometers.**—Many instruments of varying degrees of accuracy and portability are made for the purpose of measuring the intensity of illumination on a surface; they all work on the principle of comparing this illumination with that produced by a standard lamp in the instrument on an adjacent surface. One of the most convenient and simple types is the foot-candle meter. In this the comparison lamp is underneath and at one end of a row of grease spots which form part of the test surface. As they are at different distances from the light they are illuminated to different intensities and are calibrated directly in foot-candles. The intensity of illumination falling on the surface is gauged by determining which spot most completely disappears in its background.

The British Standard Specification No. 230 for portable photometers lays down an accuracy of ± 15 per cent.

62. *Size and location of light units.*

1. *Small versus large units.*—Except when semi-indirect lighting is employed, the most uniform illumination is obtained with a number of small units scattered about the room, with due regard to spacing ratio (*see* para. 6), and better switch

control is obtainable with such an arrangement. Rooms must, however, be considered according to their size; very small units look isolated and insignificant in a large room; consequently, large units must be used or small units must be bunched. Moreover, the question of cost is important, for a number of small fittings will be more costly to install than one large fitting, and, generally speaking, large lamps are more efficient than small ones.

It is not possible to lay down any hard-and-fast rules concerning the use of single lamps or cluster fittings. The final decision must be influenced largely by personal taste, the nature of the room, the arrangement of the furniture, and economical considerations.

2. *Industrial lighting.*—Under this heading is included the lighting of all workshops, machine shops, engine rooms and similar buildings; efficient lighting in this class of building is of more vital importance than in any other class. Inadequate and unsuitable illumination is not only highly prejudicial to the general health of the workers, but it is also responsible for a large number of accidents, for diminution in output of work, and for lack of discipline. Bad lighting affects output unfavourably, not only by making good and rapid work more difficult, but also by causing headaches and the other effects of eye-strain.

Some years ago the Home Office appointed a committee to enquire and report as to the conditions necessary for the adequate and suitable lighting (natural and artificial) of factories and workshops, having regard to the nature of the work carried on, the protection of the eyesight of the persons employed, and the various forms of illumination. Two reports of this committee have been published and the fundamental requisites of good lighting have been summarized as follows in Welfare Pamphlet No. 7 issued by the Home Office :—

i. **Adequacy** :—
  - (*a*) For affording safe access from one part of a work-room to another.
  - (*b*) For efficient carrying on of the work.

ii. **Suitability**, comprising :—
  - (*a*) A reasonable degree of constancy and uniformity of illumination over the necessary area of work.
  - (*b*) The placing or shading of lamps so that the light from them does not fall directly on the eyes of an operator when engaged on his work, or when looking horizontally across the workroom.
  - (*c*) The placing of lights so as to avoid the casting of extraneous shadows on the work.

No hard-and-fast rules can be laid down for all workshops, but an application of the principles in the pamphlet and this chapter, together with the suggested intensities of illumination in Sec. **59**, should produce satisfactory results. The B.S. industrial reflector previously referred to can be recommended.

In stores, dumps, and elsewhere good lighting is of the greatest value in preventing unauthorized persons removing articles and in assisting the police in their duties.

3. *Offices*.—In large offices, where a number of clerks are employed on routine work, a more or less even distribution of light over the whole room should be aimed at, with an average intensity of at least 2½ foot-candles. Semi-indirect lighting is coming into favour for this class of work, and it possesses the merit of giving little reflective glare from documents and books.

In small offices it will usually be found that local lighting over individual desks, with a greater maximum intensity than in larger offices, will be most suitable. Shading and glare must be very carefully attended to, and care should be taken that the illumination comes from the right direction, *i.e.*, from very slightly behind and to the left of the worker. This latter principle applies in every case of local lighting.

Drawing offices constitute special problems. From **3** to 10 foot-candles may be necessary according to the class of work. Direct lighting, with very careful shading and location of the lights, is preferable for the more intricate work ; semi-indirect or indirect lighting, with their comparative absence of shadow, have certain claims for ordinary work, though the draughtsmen who will welcome such lighting are few. Fittings of the " Daylight " or " Restlight " type give the most satisfactory illumination for drawing offices and are now authorized by the Barrack Synopsis (*see* Sec. **63**).

4. *Domestic lighting*.—In certain rooms the position of the lamps is practically fixed by the use to which the room is put.

In bedrooms at least one lamp should be situated over the front edge of the dressing-table, though a 2-light pendant, with the lamps spaced about 20 inches apart, is preferable. A local light, such as a well-shaded portable lamp at the bedside, should also be provided.

In a dining-room the majority of the light should be concentrated on or over the table, with a local light over the sideboard. Exceptions to this rule may have to be made in the tropics, where flying insects, attracted by the light, are liable to fall into the food. If an adjustable pendant is employed it should be well shaded, and two, three, or more lamps are better than one, of equivalent lumens, for the reason that different degrees of illumination are obtainable. If coloured silk shades are employed they should be white-lined, to avoid undue loss by absorption. Silk shades are expensive, and are not supplied at public cost.

In living-rooms flexibility should be facilitated by a liberal provision of wall sockets to enable movable or portable fittings to be readily placed in the exact positions required. It will usually be necessary to provide some general illumination in addition, and a combination of a central semi-indirect unit with well-shaded smaller units (*e.g.*, wall brackets or standard lamps) is recommended.

Kitchens, pantries, and sculleries deserve far more attention than they usually receive. In the first-named, a really good general illumination is essential, special care being taken to ensure that persons cooking are not standing in their own light and can see into the oven. In a scullery, a light immediately over the sink is the main consideration, and much the same remark applies to a pantry, though some general illumination will be required in addition.

In the lighting of stairs, the points to be aimed at are (*a*) avoidance of " light-in-the-eye " when ascending or descending, and (*b*) light to be so directed that one step does not cast a shadow on the next. If possible, the source of light should be to one side of the staircase.

There are always some obscure recesses, corners, cupboards, cellars, &c., where light is only occasionally or seldom required ; but, nevertheless, provision should be made for lighting such places, either by the installation of extra lights or by suitable location of the lights in the passages, &c. It should never be necessary to use candles, oil lamps, matches, or even portable lamps.

Again, lamps are not provided nearly so often as they should be in courtyards, enclosures, out-houses, &c. Weatherproof fittings are available for such places, and arrangements can be made for the control or master-control of the lights from the main buildings.

5. *Barrack lighting.*—In the lighting of barrack buildings the same general principles apply as in domestic lighting.

In connection with barrack rooms it should be noted that the beds are almost invariably placed near the walls and the tables down the centre, and that as much light is required at a corner bed for reading purposes as in the centre of the room. Hence, unless semi-indirect lighting is employed, two rows of light are better than one, where considerations of economy permit.

In *ablution rooms*, it will usually be unnecessary to provide any lights other than those immediately over the ablution benches. One 25W lamp per 10 feet of bench will normally be sufficient.

In *cookhouses* the location of cooking stoves, &c., will determine the best position of the lamps.

In *bathhouses* it will frequently be possible to make one light serve two baths.

6. *Spacing.*—Wherever a room is large enough to have more than one light, a good arrangement, after having found the total number of lumens required, is to divide the ceiling into a number of imaginary squares and to place a light unit in the centre of each square. In selecting the type of fitting to install, the foremost consideration is the height-spacing ratio. If this is correct and the room is of a convenient shape to divide into squares a reasonably uniform illumination is assured, and it should be noted that the more efficient direct-lighting units can be utilized, provided that they be put at such a height as to be well outside the normal range of vision.

Approximate spacing ratios for the three types of reflector mentioned in Sec. **60**, para. 3, are as follows :—

Type of reflector.	Spacing ratio.	
	Distance apart.	Height above working plane.
Extensive	2	1
Intensive	1·5	1
Focusing	1	1

The actual values are not standardized, but depend upon the makers of the fittings (*see* Sec. **60**, para. 4).

Another point to be noted is that it is nearly always better to employ two or more rows of light than one row, on account of the awkward shadows likely to be cast by the latter.

The following example will make these principles clear :—

Example.—Suppose that light has to be provided in a factory, 100 feet by 50 feet, that the work is machine assembly, that an average general illumination of 2 foot-candles is desired, and that the supply is at 230V.

The net lumens required = 2 × 5,000 = 10,000.

Taking the average utilization factors suggested in Sec. **61**, para. 4, the gross value required will be ;—

i. *For direct lighting*, $\frac{10,000}{0\cdot5} = 20,000$ lumens.

ii. *For semi-indirect lighting*, $\frac{10,000}{0\cdot4} = 25,000$ lumens.

iii. *For indirect lighting*, $\frac{10{,}000}{0\cdot 3} = 33{,}000$ lumens.

Indirect lighting can be dismissed at once. It is unduly extravagant, and few factories possess ceilings suitable for its employment.

The total area can be divided into two 50-foot squares or eight 25-foot squares.

Using *semi-indirect* lighting, two 500W lamps (15,400 lumens) would not be sufficient, whereas two 1,000W lamps would give much more light than is necessary. Four 300W lamps (17,040 lumens) would give insufficient light and cannot be evenly spaced. Eight 200W lamps (21,280 lumens) might give enough light; but the cost of the fittings would be high.

Using *direct* lighting, eight 200W lamps (21,280 lumens) would give the amount of light required and can be suitably spaced, so this system would be selected provided that sufficient height is obtainable. For intensive reflectors a height of $25 \times \frac{1}{1\cdot 5}$ feet, *i.e.*, 16 ft. 8 in., above the working plane would be required, whilst for extensive reflectors a height of $25 \times \frac{1}{2}$ feet, *i.e.*, 12 ft. 6 in., would be sufficient.

If it is impossible to place the units 12 ft. 6 in. above the working plane, it would be necessary to employ a larger number of small units placed closer together. Sixteen 100W lamps (18,240 lumens) would probably suffice.

63. *Special methods of lighting.*

1. *Local and general lighting.*—Broadly speaking all lighting schemes can be divided into two classes :—

(1) *General lighting*, where the entire area under consideration is illuminated as evenly as possible. This usually involves the use of a few large fittings.

(2) *Local lighting*, where light is concentrated at the spots where work is usually carried on, and a smaller intensity of illumination provided for the rest of the room.

Where high intensities of illumination are desired, as in compositors' rooms, economy usually necessitates some form of local lighting, but in a good many cases in workshops and drawing offices a decision is difficult. The relative advantages of each may be summarized as follows :—

Local lighting.

i. A high intensity may be readily obtained.

ii. The lights can be separately controlled, and in some cases this leads to economy; *e.g.*, when only a few people are in a room only those lights which are strictly necessary need be turned on.

iii. Lights can be made adjustable so as to suit the needs of each worker.

iv. On the whole more economical in current consumption.

General lighting.

i. Cheaper to install, because the lighting points are fewer.

ii. Less trouble to clean and maintain.

iii. Less contrast, and consequently less danger of accident and less eye strain.

iv. Pleasanter appearance both by day and by night.

v. More or less independent of the position of the furniture.

General lighting with a few judiciously placed wall sockets is a very good compromise in most circumstances.

2. *Forms of corrected light.*—By using a filter screen of special glass the light from a metal filament lamp may be altered in colour until it approximates to some form of daylight. For matching colours the closest possible approximation to the light from an overcast north sky is essential, but filters have a much wider application than this. Daylight is unquestionably much pleasanter to work in than any artificial light, and in many places, in particular *drawing offices,* the installation of some form of corrected light is worth considering. Many firms make fittings in which the light is partially corrected, though not sufficiently for colour matching, and the result of installing these fittings is very pleasant and efficient.

They are expensive in first cost and also in running expense, as the filters function by absorbing most of the red rays, and in consequence anything from 50 to 75 per cent. of the lumens emitted by the light. This disadvantage is to some extent counteracted by the fact that visual acuity with this light is about twice as great as with uncorrected artificial light.

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CHAPTER VIII.

ELECTRIC LIGHT FITTINGS AND LAMPS.

64. *Summary.*

The following appliances form part of every electric light installation, and will now be considered :—

i. Appliances for converting electrical into luminous energy. *Lamps* (Shades and Reflectors have already been dealt with).
ii. Holders for lamps and fittings for connecting lampholders or flexible leads with the main wiring. *Lampholders, Ceiling Roses, Wall Sockets,* &c.
iii. *Switches.*
iv. Protective gear for cables and wires in the event of a short circuit or other heavy excess of current. *Fuses.*
v. Arrangements for housing fuses in groups and of gaining access to the different sub-circuits for testing, &c. *Distribution Boards.*

65. *Incandescent lamps.*

1. **Incandescent electric lamps** are mainly of the filament type. Although other materials have been tried from time to time, *carbon* and *tungsten* only are now in use to any extent.

The filament is raised to a high temperature by the passage of the current, and to prevent oxidation it is enclosed in a glass bulb from which the air has been exhausted, or which is filled with an inert gas.

Theoretically, the higher the temperature the greater the amount of light radiated ; but, practically, the temperature is limited by the rate at which the filament disintegrates, and thus loses cross-section and obscures the bulb. The higher the temperature the greater the efficiency, but the shorter the life. It is usual to design for a life of 1,000 hours.

2. **Carbon filament lamps.**—The efficiency of carbon filament lamps is poor, owing to the comparatively low temperature (1,800° C.) at which they can be worked. This is due to the volatile nature of carbon at high temperatures. The filaments cannot be worked at anything approaching the fusing point of carbon, which is extremely high, owing to the rapid blackening of the bulb.

The practical energy consumption is about **4–5W** per m.s.c.p.

Owing to the fact that carbon has a negative temperature coefficient, a small variation in supply voltage makes a large difference in candle-power (*see* para. 7). Carbon filament lamps are only used in a few special cases, where efficiency is not of great importance or in fittings liable to rough handling such as portable lamps. Carbon lamps are more robust than metal filament lamps in small sizes.

3. Tungsten filament lamps.—Tungsten has an exceptionally high melting point (3,400° C.), and it can be drawn into fine wires with a mechanical strength exceeding that of the highest grades of steel wire.

The limiting working temperature for a life of 1,000 hours is about 2,100° C. when the filament glows in a vacuum, and 2,400° C. when the bulb is filled with inert gas (usually argon at about half atmospheric pressure when cold, and at atmospheric pressure when hot). The increased working temperature accounts for the higher efficiency of *gas-filled* lamps. The presence of the gas reduces the rate of evaporation of the filament, but introduces a certain amount of cooling effect through conduction and convection. To reduce this loss, the filament of gas-filled lamps is wound in a close spiral ring, and to minimize blackening of the bulb the larger lamps are made with a long neck, which remains at a lower temperature than the parts near the filament, and the volatilized tungsten particles are carried up by convection and deposited mainly on the neck portion of the bulb.

Tungsten *vacuum* lamps usually have hair-pin or long, squirrel-cage filaments. They are now seldom met with except in the smaller (15W and 25W) sizes.

Owing to the comparatively low resistance of metals, the filaments must necessarily be long and thin. The smallest standard lamp at the present time is the 230-volt, 15W vacuum lamp, which has a filament only 0·015 mm. in diameter.

" Frosted " and " Opal " lamps.—To reduce the surface brightness of metal filament lamps, modern practice favours the use of lamps with " frosted " or " opal " glass bulbs. The " frosting " may be outside or inside, but whereas outside frosting reduces the m.s.c.p. by 5 to 10 per cent. even when the lamp is new, and moreover rapidly becomes dirty when in use, and so still less efficient, internal frosting reduces the m.s.c.p. by about 2 per cent. only. The internally-frosted lamp known as the " *Pearl lamp* " is now the British standard type for all sizes up to 100W. Although costing a little more to manufacture, they are sold at a lower price than clear lamps, in order to encourage their use and so enhance the reputation of electric lighting.

With " Pearl " lamps the filament can still be distinguished, but in lamps with " opal " bulbs the filament is quite obscured, and the result is very pleasing. Unfortunately, there is a loss of light of about 20 per cent. (*cf.* 2 per cent. for internally-frosted lamps), and moreover the lamps cost about 20 per cent. more.

In sizes above 100W, lamps are standard only with clear bulbs, but such lamps should only be used in fittings which obscure the filament.

4. Rating of Tungsten metal filament lamps.—The dimensions, performance, etc., of these lamps is governed by B.S.S. 161.

As previously stated, standard lamps up to 100W have internally-frosted bulbs, and above 100W clear bulbs. Clear lamps of small candle-power can be obtained if required for certain directive types of fitting, but they are more expensive than the internally-frosted lamps.

The specification calls for certain standards of performance, but for " general service " it does not specify the method of construction. At the present time, the only vacuum lamps in the " general service " list are the 15W, 100–130V, and the 15W and 25W, 200–250V. As a concession to certain makers of special fittings, there is also a standard 40W vacuum lamp with a clear bulb for voltages of 200–250V.

The figures in Table **J**, which have been taken from B.S.S. 161, will give some idea of the specified performance of the most common sizes of " general service " lamps.

TABLE J.—*Standard sizes and efficiencies of metal filament lamps*

Size watts.	Voltage.	Initial lumens.	Efficiency (lumens per watt).		Initial m.s.c.p.	Initial efficiency (watts per m.s.c.p.).	Bulb.
			Initial.	Life average.			
15	115–130	123	8·2	7·35	10	1·5	Internally frosted.
	230	106·5	7·1	6·7	8	1·87	
25	115–130	215	8·6	7·74	18	1·39	do.
	230	200	8·0	7·2	16	1·56	
40	115–130	416	10·4	9·36	34	1·18	do.
	230	324	8·1	7·13	26	1·54	
60	115–130	720	12·0	10·8	58	1·03	do.
	230	582	9·7	8·73	46	1·30	
75	100–130	960	12·8	11·52	76	0·99	do.
	230	795	10·6	9·54	63	1·09	
100	100–130	1330	13·3	11·97	106	0·94	do.
	230	1160	11·6	10·43	92	1·19	
150	100–130	2130	14·2	12·78	170	0·88	Clear.
	230	1920	12·8	11·52	150	1·00	
200	100–130	2960	14·8	13·32	235	0·85	do.
	230	2660	13·3	11·97	210	0·95	
40 (vacuum)	230	348	8·7	8·1	28	1·43	do.

The only other standard sizes are 300, 500, 1,000 and 1,500W. The initial efficiency of the latter reaches 18·6 lumens per watt (0·68 watt per m.s.c.p.) in the 230-volt type. The loss due to internal frosting of the bulb is allowed for in the table. In the case of lamps with opal bulbs the lumen and efficiency figures must be modified by a percentage to be declared by the manufacturer to allow for absorption.

5. Tolerances.—The figures given in Table **J** are "*rated*" values based on an *average* life of 1,000 hours, but a fairly large tolerance is allowed. For example, a nominally-rated 40W, 230-volt, lamp complies with the specification if its initial performance figures are from 35 to 45 watts, 275 to 373 lumens, and 7·29 to 8·91 lumens per watt.

6. Life testing of lamps.—As the life of a lamp varies inversely as about the 7th power of its efficiency, B.S.S. 161 standardizes the test by saying that it shall be conducted at the voltage which produces the mean efficiency, or else lamps for the test must be selected ones, having approximately the mean efficiency at the rated voltage.

The selected batch of lamps is run until the average life attains 1,000 hours, or until the average lumen efficiency falls just below the life average figure given in Table **J** (subject to a tolerance of 3 or 4 per cent.).

For full particulars, the specification must be referred to.

B.S.S. 161 deals also with low-voltage metal filament lamps for train and vehicle lighting.

7. Over and under-running.—A change in the voltage applied to a lamp will alter its filament temperature and consequently its life and candle-power. The amount of these changes is much greater than the change in the voltage as the following figures show (percentages in all cases) :—

Voltage.	Carbon filament.	Metal filament.		
	c.p.	c.p.	Power consumption.	Life.
±1	± 6	± 4	±1·7	∓13
±4	±22	±15	—	−37 +65
±10	—	+40 −33	±17	—

The cost of providing a definite illumination for a given period consists almost entirely of the cost of energy and the cost of lamp renewals, and both these are seen from the preceding table to be dependent on the voltage applied to the lamp; if it is overrun (*i.e.*, run at more than its rated voltage) its efficiency is increased while its life is decreased. If a curve is plotted of the total cost of the illumination against the voltage it will be in the form of a V, and its minimum will give the most economical voltage at which to run. For any lamp this voltage will vary according to the cost of the lamp and the cost of energy, and will not necessarily be the same as the rated voltage of the lamp. Thus where energy is expensive and lamps very cheap it would theoretically pay to use lamps on a higher voltage than their rated voltage, and where lamps are expensive and energy cheap to " under-run " them. In practice limitations imposed by standard sizes only being available, the nuisance of frequent renewals, and the ± 4 per cent. voltage variation allowed, make it unwise to put this policy into effect except in a very few extreme cases of cheap energy and expensive lamps. Great care must be taken never to over-run lamps.

When the filament of a vacuum lamp breaks, it may be possible to fuse the broken filament together again by tapping the bulb when the current is switched on. This process may be utilized to give a temporary service; the subsequent life of the lamp, however, will be short, since the filament has, of course, been shortened, and, consequently, the lamp will be over-volted.

8. **Care of lamps.**—It must be emphasized that all metal filament lamps are fragile, and that the higher the voltage and the lower the candle-power the greater is the fragility. The following rules should be carefully observed in order to avoid unnecessary breakages :—

i. Great care should be taken when replacing a worn-out lamp by a new one; many lamps are broken while being placed in the lampholder.
ii. Lamps should not be cleaned when switched on, since the filament is more fragile when hot than when cold, and there is also danger from shock.
iii. Lamps should never be touched, except by the authorized persons for cleaning and replacement.
iv. Lamps should not be switched on and off unnecessarily.
v. In positions subject to excessive vibration, lampholders should, if possible, be suspended from flexible wire and not fixed direct to brackets or back-plates, unless special anti-vibration attachments are provided.

9. **Arc-incandescent lamps.**—This type of lamp, known as a *Pointolite*, is manufactured by the Edison Swan Electric Company, Ltd., and forms an intermediary between incan-

descent and arc lamps. The general construction is indicated in Fig 53, where T is a solid ball of tungsten, from which the light is emitted, and AB is an ionizing rod of certain rare metals. The bulb is filled with nitrogen or argon. To start the lamp the switch is closed, and the current passing through the ionizer raises it to incandescence at a temperature sufficient to ionize the gas between it and the positive electrode, T. One or two seconds is sufficient for ionization, and when the switch is released the arc is struck between the tungsten ball as anode and the ionizing filament as cathode.

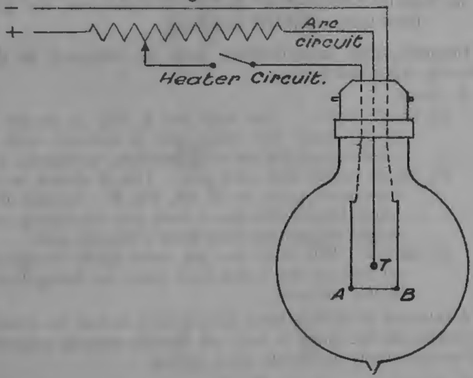


Fig. 53.

Pointolite lamps can be supplied for use on A.C., but the type here described is suitable for D.C. only, and can at present be obtained in sizes of 30, 100, 500, and 1,000 candle-power only. A starting resistance box is also necessary, so it is rather expensive, but the point source gives it special advantages for projection work. It consumes about 0·5W per candle-power, and the average useful life of the 100 candle-power type is about 400 hours at that rate of consumption. If run until the globule has entirely sputtered away the life is from 600 to 1,000 hours. On the other hand, its efficiency may be increased, at some expense to its life, by increasing the current.

10. **Neon lamps.**—Although not *incandescent* lamps, neon-filled lamps, emitting a pink light from glowing electrodes instead of filaments, are of limited use as tell-tale lights and night lights, owing to their low consumption. With D.C., only one electrode glows. They are made in 5-watt sizes for a range of 200–250 volts only.

66. *Lamp fittings.*

1. **Lampholders** are of four general types, viz. :—

- i. Small bayonet-cap (S.B.C.) lampholders, for miniature lamps and candle lamps.
- ii. Bayonet-cap (B.C.) lampholders for all ordinary vacuum lamps and gas-filled lamps up to and including 150W.
- iii. Edison-screw (E.S.) lampholders, for gas-filled lamps of 150W and 200W.
- iv. Goliath-Edison-screw (G.E.S.) lampholders, for gas-filled lamps of 300W and over.

Bayonet cap lampholders may be obtained in the following types and forms :—

A. *Brass.*

- (*a*) Shade carrier. One end has a ring to secure a shade, while the other end is screwed with a $\frac{5}{8}$-inch thread for use with brackets, standards, &c.
- (*b*) Shade carrier and cord grip. This is shown in its component parts on Pl. **95**, Fig. 2. Instead of a $\frac{5}{8}$-inch thread this has a cord grip for taking the weight of a fitting hung from a flexible cord.
- (*c*) Batten. This form has the same shade carrier as (*a*) and (*b*), but a flat back plate for fixing direct to flat surfaces.

A common fault with brass lampholders is that the pinching screws are too small to hold the flexible strands properly and are not easily accessible when wiring.

B. *The Scott type.*—This is also made of brass and is shown on Pl. **95**, Fig. 1. It has the following advantages over the ordinary type :—

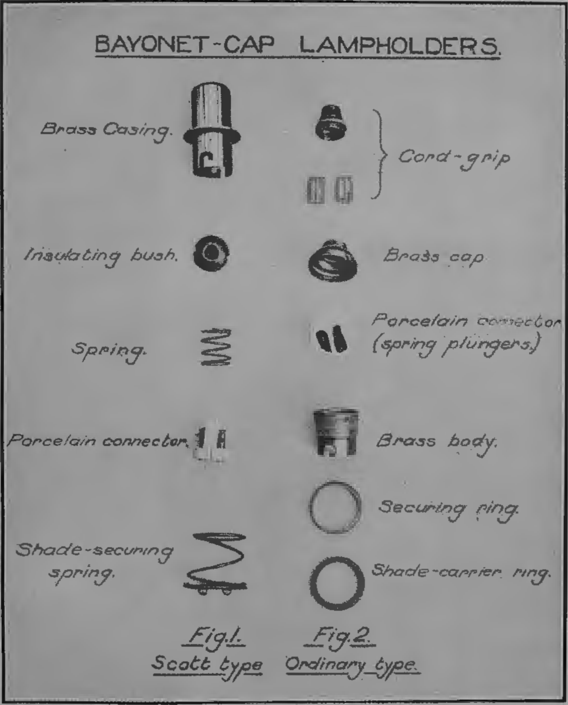
- (*a*) Fewer component parts.
- (*b*) No spring plungers carry the current.

C. *Bakelite* (*see* Fig. 2, Pl. **96**).—In the present state of their development, Bakelite and similar materials are not yet equal to porcelain from an electrical point of view. For this reason, fittings made of these materials are not, at present, in any D.W. Contract Circular. They are being gradually improved, however, by various makers, and it is possible that, in the near future, they may largely supersede porcelain and brass in electric fittings.

A less fragile material than porcelain is badly needed, and the less metal there is about a fitting the better from a *shock* point of view.

B.C. lampholders which include a key-switch can also be obtained. The switch should preferably be of a pattern which

PLATE 95.



BAYONET-CAP LAMPHOLDERS.

Fig. 1. Scott type

Fig. 2. Ordinary type.

INSULATED CEILING ROSE AND LAMPHOLDER.

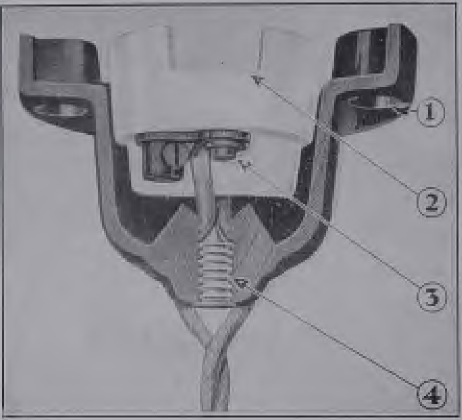


Fig. 1.—1. Fixing holes suitable for standard conduit boxes. 2. Adaptable for surface wiring by removing small portion of rim of rose. 3. Terminals with ample room for looping in. 4. Quickly wired cord grip.

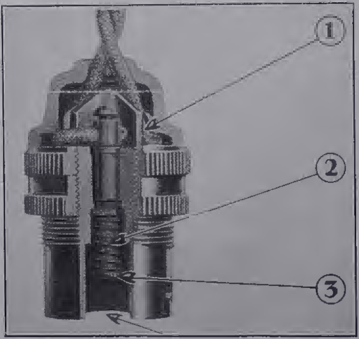


Fig. 2.—1. Cord grip suitable for all types of flexibles. 2. Non-rusting alloy springs. 3. Solid plungers.

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[To follow plate 96.

PLATE 97.

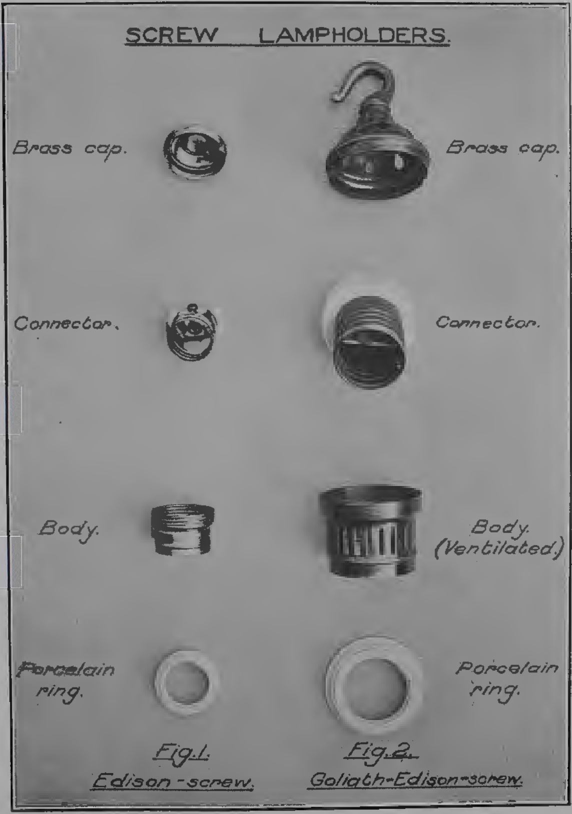

PLATE 98.

CEILING ROSES.

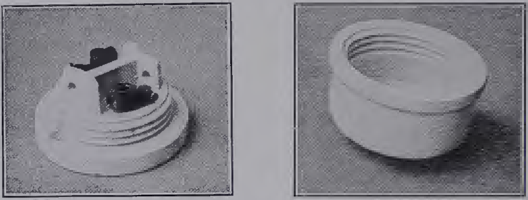

Fig. 1.—Ordinary two-plate.

Fig. 2.—Cleat-wiring.

is actuated by a pressing rather than a twisting motion, as this is less severe on the flexible wire and the mechanism is much more reliable.

In passages, washhouses, stables, and places of a semi-open nature, lampholders should be fixed to a length of conduit or bracket and not allowed to hang on a long flex.

The ordinary type of lampholder must only be used in dry situations. Where it is damp and in factories and workshops, the Home Office type of insulated lampholder must be used. The H.O. Memorandum on workshop lighting directs that the design shall be such as to " enclose the lampholder entirely with insulating material so that neither it nor the metal cap of the lamp can be touched." These insulated lampholders are about double the price of the ordinary type.

The use of lamplocks is strongly recommended in situations where pilfering and other interference is likely to occur. Unauthorized apparatus and lamps of high candle-power are usually put carefully out of sight before any inspection can take place.

The Brook lamplock is made in two types for the ordinary and H.O. lampholders. It requires a special key, but definitely locks both fitting and lamp. The Francis lamplock can only be used with an ordinary lampholder, and does not prevent the brass body of the lampholder from being detached from the cap. To remove the lamp it is necessary to break the bulb.

Edison-screw and **Goliath-Edison-screw lampholders** (iii and iv), which are standard for the higher-current lamps, differ from B.C. lampholders in that one contact is made through a flat spring in the centre and the other through the cap into which the lamp is screwed. They are illustrated in their component parts on Pl. **97.**

2. **Connectors and ceiling roses.**—The use of connectors as opposed to jointing or looping-in is discussed in Chap. IX. Ceiling roses are used to connect the main wiring to the flexible cord in the case of pendant fittings, and connectors are usually designed to be used as ceiling roses if necessary. Provision must be made to relieve the actual connections to the flex of the weight of the pendant ; the custom of tying a knot in the flex in order to take the weight on the rose cover is bad for the flex and should be forbidden.

Ceiling roses may be obtained with two, three, or four plates, according to the number of connections to be made. Pl. **98** shows two types of two plate roses. Fig. **2** depicts a special kind made for Cleat or T.R.S. surface wiring.

The Bakelite ceiling rose illustrated at Fig. **1** on Pl. **96** is recommended for new work. It will be noted that the base is of porcelain.

In selecting connectors and ceiling roses the following qualities should be looked for :—

(1) The base should be of durable, rigid, tough, non-inflammable, non-absorbent, insulating material. Porcelain vitrified throughout satisfies these requirements, but cannot be drilled for fixing, and so must usually be mounted on a base block of hard wood. The cover need not be of vitreous porcelain if it is kept clear of the terminals.

(2) Brass terminals and setscrews should be substantial, and room allowed for two or three separate conductors without twisting.

(3) Insulating pillars between terminals of opposite polarity must be provided.

(4) For T.R.S. wiring there should be a large diameter central hole for the entry of conductors to avoid the necessity of stripping the outer sheathing.

Practically every firm of cable makers supply a special connecting box for use with their wiring system. Some of these are of tough moulded material such as Bakelite, for use with insulated wiring systems. They are workable and neat, and no wood base block is needed.

In slightly damp situations ordinary connectors can be used if special precautions are taken. Wood base blocks must be rendered non-hygroscopic by varnishing or impregnating with paraffin wax, and packed out from the wall. The interior of the box must be painted throughout with shellac, the cable braiding stripped well back, and the rubber ends sealed with Chatterton's compound. Careful soldering of the conductors will also help to prevent moisture creeping along the strands.

In very damp and corrosive places special watertight and gastight connectors must be used. These fittings are of non-hygroscopic composition and the terminals are isolated in an air lock from atmospheric influence, the box being filled with a sealing compound, or else made airtight and fitted with cable glands.

The K.M. connector (Pl. **99**, Fig. 5) is good for dry situations, but a little on the small side for T.R.S. wiring.

3. **Wall plugs and sockets** are used to connect the sub-circuit wires to the flexible wires in the case of standard, desk, and table lamps, and other portable fittings.

B.S.S. 372 deals with two-pin and three-pin plugs for domestic purposes, and provides for standard ratings of 2, 5, 15, and 30 amperes.

K.M. CONNECTOR.

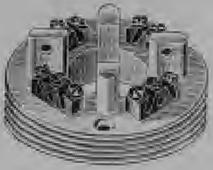

Fig. 1.—Porcelain Base.

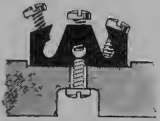

Fig. 2.—Brass Terminal Block.

Fig. 3.—Plain Cover.

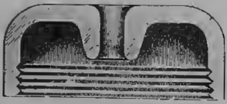

Fig. 4.—Cord Grip Cover. (Ceiling Rose.)

Fig. 5.—Connector Fitted up as a Ceiling Rose.

Particular attention is drawn to the following requirements :—

i. The contact tubes shall be recessed in the insulating base so that it is impossible to touch them unintentionally.
ii. Base to be of vitreous material or tough, incombustible insulating material.
iii. Plug to be of tough, incombustible insulating material.
iv. Plug to be provided with a hand shield.
v. Plug to be designed for side-entry of flexible cord with provision for gripping the cord.
vi. A hand grip to be provided for withdrawing the plug without subjecting the cable or its sheathing to any stress.

The Electrical Contractors' Association recommend the use of 3-pin plugs throughout. They say : " In view of the large percentage of cases in which portable standards and domestic appliances may have to be earthed under I.E.E. Regulations 96, 100, and 106, together with the fact that all such have to be provided with an earthing terminal in case same should be required under the Regulations (*see* Regulation 103) it appears very desirable that only 3-pin hand shield plugs should be used for all purposes on all pressures exceeding 100 volts D.C. and 30 volts A.C., and that in future non-interchangeability where desired between power and lighting sockets should be obtained by using 2 ampere size 3-pin type plug and socket exclusively for lighting purposes, and the 5, 15, and 20 ampere 3-pin exclusively for power purposes."

This recommendation is sound, but must obviously be interpreted with discretion. When adding plugs to an existing installation the question of interchangeability must be considered.

The Regulations do not place any restrictions on the position in which wall sockets may be installed (except in garages, where the height must not be less than 6 feet), and the installation of a switch with the socket is not compulsory below 5 amperes. For W.D. purposes, however, a switch should always be provided. It may be either alongside the wall socket or placed close to the other switches in the room.

It is recommended as a general rule that wall sockets should be installed about four to five feet from the floor.

Where the expense involved is reasonable a separate branch circuit should be provided for wall sockets.

When a plug connection is to be used for purposes such as charging small accumulators where correct polarity is a matter of importance, plugs with differently shaped contacts should be used.

4. Other fittings.—The fittings already described have been taken as types of those used in all lighting installations. A detailed description of the many other fittings which might be used cannot be given here; they will be found fully described and illustrated in makers' catalogues.

Elaborate fittings should be avoided. In the majority of cases in barrack lighting, it will not be necessary to use other than those detailed in D.W.S.S. No. 12 and in D.W. Contract Circulars.

Every wall plug and socket, or group of wall plugs and sockets, must be independently controlled by a fixed switch on the live side. If a switch lampholder were the sole means of control, then the flexible wires would be permanently live, so long as the wall plug was in position. Consequently, most manufacturers produce a fitting which is a combination of wall plug and switch; many of these combination fittings have an interlocking device to ensure that the switch is off whenever the plug is withdrawn from the socket.

If strict compliance with the I.E.E. Regulations be insisted upon, not only must switch lampholders be controlled, preferably in groups of not more than 10, by a wall-switch, but every such group must also have at least one lamp controlled solely by the wall-switch.

67. *Switches.*

1. Functions of switches.—The general subject of switching is dealt with in Sec. **75.** The following switches are necessary in any electric light installation :—

i. *Main switch.*—To control the whole current supply to the installation. A double-pole switch is necessary, placed as shown in Fig. **54.** Two single-pole tumbler switches coupled with a wooden handle may be used in emergency, but the practice is undesirable.

ii. As is mentioned in Sec. **69**, single-pole switches are desirable on all distribution boards which feed other d.b.'s through sub-mains; the final d.b.'s need no switches, though they may be provided where a general control of the sub-circuits is required, *e.g.*, Barrack blocks.

2. Types of switches.—The switches that are most commonly employed in electric light installations are of the following types :—

i. *Knife-blade switches* are used in the double-pole form for main switches and are obtainable in a variety of designs. A quick break is ensured either by means of follower-blades attached to the main blades by springs, or by coupling the main blade to the handle

TUMBLER SWITCHES.

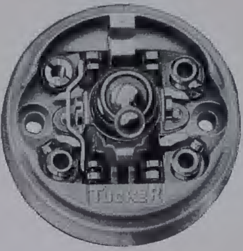

Fig. 1.

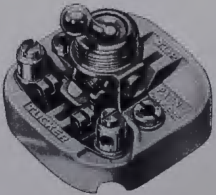

Fig. 2.

[*Permission of Messrs. J. H. Tucker & Co., Ltd. Tysley, Birmingham.*

by means of a spring. The quick break action is identical with that of the field breaking switch shown in Pl. **7**.

ii. *One-way tumbler switches* are usually employed for all distribution board and point switches.

These switches vary considerably in detail, but an illustration of a good type is shown on Pl. **100**, Fig. 2. A flush-pattern switch has been chosen for illustration in preference to the ordinary pattern, as the details are more easily discernible. The mechanisms of the two patterns are identical.

The switch operates by the bridging of the fixed contacts by the moving contact. The break is positive, *i.e.*, the moving contact is pulled out by the handle and not pushed out by the action of a spring, as is often the case in small tumbler switches. A small spring assists the rapidity of the make and break and prevents the switch remaining in intermediate positions.

A quick make and break is essential.

iii. *Two-way tumbler switches* are necessary where alternative control from two points is desired (*see* Sec. **75**). The general appearance of a good type of two-way switch is shown on Pl. **100**, Fig. 1. It will also be noticed that the two contacts at one side of the switch, *i.e.*, one of each pair of contacts, are connected together and to a common terminal, the other contacts being connected to separate terminals.

Two-way switches are also constructed with an off position in addition to the two positions indicated above, and pendant forms of each type are obtainable.

iv. Various other types of switches are obtainable, *e.g.*, intermediate switches for use when alternative control from more than two positions is desired, three-way switches, &c.

3. Design of switches.—The essential points of a good switch are as follows :—

i. Overheating must not take place at the point of contact or elsewhere when the full current flows continuously. Thus the actual contacts should be springy, not stiff and unyielding, and there should be no chance of contact being made through a point only. Also the current density in any part should not exceed 500A per square inch.

ii. It should be impossible for contact to be made accidentally when the switch is left open, or for the contact piece to remain in any position except full-on or full-off.

iii. The break between moving and fixed contacts should be large enough to preclude the possibility of the formation of a permanent arc when breaking circuit. All switches should be tested with voltages and currents 50 per cent. in excess of those for which they are rated.

iv. The break should be positive in action, *i.e.*, the switch should not depend on the action of a spring to break contact, though a spring is commonly used to ensure that the break shall be rapid.

v. The bases should be of incombustible, non-conducting, moisture-proof material.

vi. Covers should be of incombustible material, and must be either non-conducting or of rigid metal and clear of all internal mechanism. At voltages exceeding 125V, metal covers should be lined with insulating material.

vii. Thimble sockets or other devices for the connection of cables or wires should be large enough to take the conductor of the cable or looped wire without reducing its area.

The ordinary type of tumbler switch should only be used in dry situations. The cheapest has a metal dolly and screw on cover, which should preferably be of steel bronze or copper bronze owing to the objectionable practice of polishing brass. In conduit installations, the switches in barrack rooms, store rooms, passages, and in all places where there is particular liability to damage, iron-cased switches should be used, and the switch box should be screwed direct on to the wall and not depend upon the tubing for support. Sunk type switches are recommended in officers' quarters and in other places where unobtrusiveness is desired. Plates for this type can be obtained in all kinds of materials and colours. "*Tucker's*" adjustable grid boxes are very suitable for the installation of sunk type switches. In external positions, in laundries and like places, special watertight fittings must be used. They may be of the "U" Seal or *Maconite* "Industrial Wiring" type, or they may be metal cased. If the latter, the case must be well earthed.

Single pole switches must always be placed on the unearthed side of the point controlled, in order that the latter shall be at zero potential when switched off. In insulated systems the switches should be all on the *same* side of the system (positive usually selected) in order to simplify the location of faults.

4. **Ceiling switches** are now on the market, designed to be mounted on ceilings and actuated by pulling a hanging cord. Single-way and two-way types are available. The movement is identical with that of the more ordinary tumbler switch with a dolly, and in some situations, *e.g.*, over a bed, ceiling switches are very convenient. In addition, their use effects considerable economy in conduit and wire by shortening switch runs.

68. *Fuses and cut-outs.*

1. The **object of a fuse** is primarily to prevent overheating in the circuit which it protects. Overheating will not only cause damage to the insulation of the wires, but will also involve risk of fire in the building. Precautions must, therefore, be taken in the design of fuseholders and fuseboards to ensure that the fuse will not cause the very trouble which it is intended to prevent.

The object of a fuse is attained by the melting of a metal wire, which is a portion of the circuit, when the current in the circuit reaches a predetermined maximum value. This value is so chosen that it will give a generous margin over the working current.

The **I.E.E. wiring regulations** (Reg. 68) lay down that the fuse shall be of such size that it would be melted in one minute or less (two minutes or less in the case of a lead-tin alloy fuse) by a current equal to twice the rating of the smallest cable protected by it, provided that no fuse smaller than one rated to blow at 7 amps. need be inserted in any final sub-circuit.

For the purposes of this regulation, the current carrying capacity of a flexible cord or cable shall be considered to be equal to that of a rubber insulated cable of equal cross-section. For example, the cross-sectional area of 14/0·0076 inches flexible cord is 0·0006 square inches, and V.I.R. cable of this size is rated at 2·3 amps. So on any circuit where this size of flex is used the fuse must be of a size to blow at 7 amps., the smallest necessary. A 20 S.W.G. lead-tin alloy fuse will be found to meet this requirement. Power circuits will have to be more heavily fused, and flexibles if used on these circuits must have a safe current carrying capacity of at least half the fusing current of the fuse.

2. *Materials used for fuses.*—The materials most commonly used are tin, lead, zinc, aluminium, copper, and alloys of tin and lead. Tin fuse wires can be obtained from the R.A.O.D. for currents from 1A to 100A, but this material is, as a general rule, only employed for currents under about 10A. For

SIEMENS ZED FUSE.

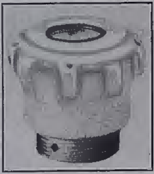

Fig. 1.—Screw-cap.

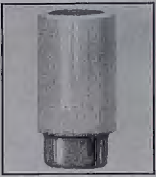

Fig. 2.—Cartridge.

Fig. 3.—Gauge Ring.

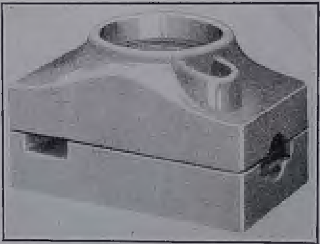

Fig. 4.—Base and Cover.

terminals, security against fire, and ease of replacement without the necessity for touching live terminals. The last point is not very important when the voltage does not exceed 100V. Above that voltage, however, a fuse wire should always be enclosed in a suitable holder, made of porcelain or other non-conductor, which can be removed bodily without any risk of shock, the ends of the fuse wire being connected to two contact pieces which fit into suitable clips on the fuse-board. Such holders exist in a large variety of shape and form.

Open type holders are dangerous and should not be used.

Service Patterns.—Standard patterns of "*Fuses*" are listed in the Vocabulary of Army Ordnance Stores, Sec. X. for 10, 20, 30, 50, 100, and 200 amp. ranges and for *low voltage only.* The component parts, viz. :—carriers (fuseholders), bases and clips, can be obtained separately. The design shown in Pl. **101**, Fig. 1, is employed for the 10 to 50 amps. sizes. Although not specified in these smaller sizes it is advisable to enclose the fuse wire in an asbestos tube to prevent the scattering of molten metal. In the 100 amp. and 200 amp. sizes, illustrated in Figs. 2 and 3 on Pl. **101**, an asbestos tube is provided.

The fuse wire passes through an asbestos tube, which prevents the molten metal being scattered and the porcelain cracking. Contacts are shielded, so that even if the fuse is replaced on a short circuit the operator cannot be burnt.

With this type of holder it is difficult to ascertain whether the fuse is intact or nor without removing it, and an indicator is sometimes fitted. One method of obtaining an indication is to connect a fine wire in parallel with the main fuse, which will blow with it and char a label on the outside of the carrier.

Fuses for medium voltage are dealt with in Sec. **12.**

Cartridge fuseholders.—An enclosed fuseholder, which has been much used, is that shown on Pl. **102.** It consists of four distinct parts, as shown, and is made in a variety of patterns to meet all kinds of fittings, and in sizes varying from 2A to 190A. After it has operated, the cartridge (Fig. 2) must be sent away to be repaired or replaced complete. Either method, of course, entails a greater maintenance cost than in the case of ordinary fuseholders. On the other hand, it possesses the advantage that it is impossible to insert a larger fuse wire than that intended. This is ensured by the gauge ring (Fig. 3), the centre of which is of such a diameter that it can only receive cartridges up to a certain size. No two sizes of cartridge have contact studs of the same diameter, and each size of cartridge has a disc of distinctive colour, which can be seen through the window of the screw-cap (Fig. 1). This disc is displaced in an unmistakable manner when the fuse blows, and, therefore, forms a reliable indicating device.

69. *Distribution boards.*

1. The **objects of a distribution board** are :—
   - i. To provide a convenient and safe means of branching sub-circuits from mains or sub-mains, or sub-mains from mains.
   - ii. To enable sections to be easily disconnected and tested.
   - iii. To house the protective fuses.

The mains or sub-mains are brought to two small *bus-bars* on the board, and the branchings are taken off these bars through a fuse on each pole. In the case of a main distribution board supplying several sub-distribution or branch distribution boards or a sub-distribution board supplying several branch distribution boards, a switch should also be provided on one pole of each pair of sub-mains ; no switches, however, are necessary on boards supplying sub-circuits to lamps, whether such boards are main distribution boards (small buildings) or branch distribution boards (large buildings). Branch distribution boards, *i.e.*, boards mounting fuses only, are frequently known as fuse-boards.

2. **Construction.**—The points to be observed in the design of distribution boards are as follows :—
   - i. The bases should be of incombustible and insulating material, and fitted with moisture-proof bushes at the points of support if the material is hygroscopic.
   - ii. The possibility of a permanent arc must be prevented, either by sufficient spacing of all live parts or by the use of separating partitions.
   - iii. All parts which may have to be handled or adjusted should be readily accessible.
   - iv. Glass fronts must be at least 1 inch from live parts, but should only be used in places where they are not liable to be broken.
   - v. Cases constructed of English oak, teak, or mahogany need not be lined, but cases constructed of other woods shall be lined with non-ignitible insulating material, which shall be clear of all live parts by not less that 1 inch.
   - vi. The bus-bars, contacts, and fuses must be so shielded as to protect a person from contact with live metal when handling the fuse carrier.

The above points are all embodied in the I.E.E. Wiring Regulations.

The best situation for a distribution board is dealt with in Sec. **87**, para. **3**, and it should also be noted that the provision of some means of ascertaining what rooms or lamps

PLATE 103.

FUSE-BOARDS FOR HOUSE SERVICES.

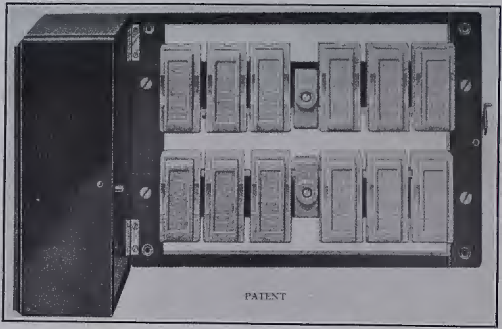

Fig. 1.—6-Way 250-Volt Board in Teak Case. Capacity: 15 Amps. each way.

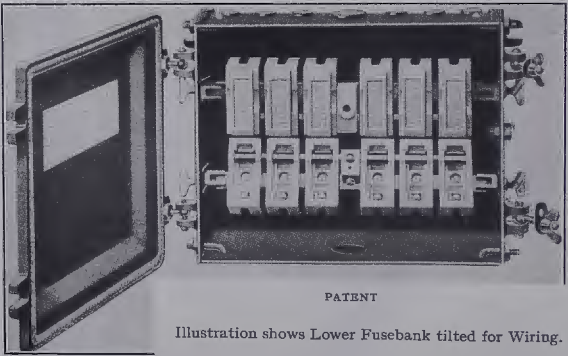

Illustration shows Lower Fusebank tilted for Wiring.

Fig. 2.—6-Way 250-Volt Ironclad Board. Capacity: 15 Amps. each way.

[Permission of M. E. M. Co.

are supplied through any particular pair of fuses, *e.g.*, a diagram on the cover of the board, is a great convenience.

3. Service patterns.—Distribution boards are described in the *Priced Vocabulary of R.E. Stores, Part I*, and may be obtained by D.W. Contract. Orders should state :—

i. Whether iron, watertight cases (for external work or use with conduit wiring) or wooden cases (for internal work) are required.
ii. Number of ways.
iii. Number of amperes per way.
iv. Whether fuses and double-pole or single-pole switches or fuses only are required.

Illustrations of 6-way fuse-boards, 15A per way, are given on Pl. **103**.

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Electrical Engineering Practice, Vol. II. J. W. Meares and R. E. Neale. 25*s*.

British Standard Specifications. 2*s*. each—

33. Carbon Filament Glow Lamps.
161. Tungsten Filament Electric Lamps.
52. Lampholders, bayonet socket.
98. ,, Goliath.
67. Ceiling Roses.
214. Distribution Boards.
372. Wall Plugs and Sockets.

CHAPTER IX.

INDOOR WIRING.

70. *General considerations.*

1. Incandescent lamps for ordinary indoor illumination are almost invariably connected in parallel; hence each lamp receives the full supply voltage across its terminals, except for the slight voltage drop due to the resistance of the leads conveying the current from the street mains to individual lamps. The leads entering a building must, therefore, be capable of carrying a current equal to the sum of the currents required by all lamps or fittings from which current can be taken, after making allowance for the demand factor.

2. Under powers conferred by the Factories and Workshops Acts, the Home Office issue regulations governing the use of electricity for all purposes in factories and workshops, but there are no official regulations for other buildings, except the Regulations of the Electricity Commissioners for securing the safety of the public. Supply companies often make rules, and inspect installations before connecting them to the mains to see that these are complied with, and Fire Offices have to be satisfied as to details before insuring buildings in which electricity is used. To set up a general standard of good practice, the Institution of Electrical Engineers issue and periodically revise "Regulations for the Electrical Equipment of Buildings." These regulations have no legal force, but should be studied and adhered to in all W.D. work, a clause to that effect being put into all contracts.

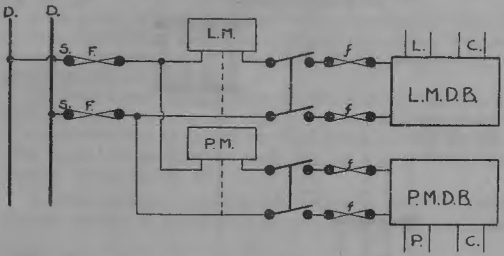
71. *Systems.*

1. **Supply.**—If an installation has its own power plant, the main control will be in the engine room, and the conductors will lead direct from the switchboard to the main distribution board of the building. If the energy is supplied by the public company or other general power station, the company will bring the service mains into the building, provide main fuses on both positive and negative sides, and fix a meter. Both the main fuses and the meter are sealed by the company. Beyond the meter the consumer has control, and he should have his own main fuses and a double-pole switch (*see* Fig. 54). Combined switches and fuses in iron boxes, arranged so that the box cannot be opened unless the switch is in the off position, are very suitable. The company's fuses may be heavy (probably capable of taking a 75 per cent.

overload), so that the consumer need not ordinarily trouble the supplier.

The point of entry will usually be chosen by the supplier to suit his own convenience, but the site of the main fuses should be dry, as fireproof as possible, and in a convenient position for the consumer's main cables. In some cases it may be convenient to lay a sub-main to a more readily accessible position for house control.

When supply is made to a barrack area by a civil supply company, the company will lay the mains to a selected feeding point within the barracks, where the main fuses and meter will be installed, and responsibility for everything beyond that point will rest with the military authorities.



DD	Main distributors.	*FF*	Main fuses (sealed).
SS	Service mains.	*ff*	Consumer's fuses.
LC	Lighting sub-circuits.	*LMDB*	Main distribution board.
PC	Power sub-circuits.	*PMDB*	Power main distribution board.
LM	Lighting meter.	*PM*	Power meter.

Fig. 54.

When a building is so large or of such a nature that a 3-wire or 4-wire supply is necessitated (*see* Sec. **32**, para. 1), and the voltage between the outers exceeds 250V, the supply must be given from pairs of terminals arranged so as to minimize the danger of shock, and the wiring from these terminals, including that behind distribution boards, must be kept distinct throughout, in separated circuits, which must not be bunched. The best arrangement at the point of entry is to have a triple-pole or four-pole linked switch, with fuses in the outer or phase wires only, and to separate from this point to two or three main distribution boards, 6 feet apart.

2. **Distribution board system.**—For the distribution of

energy within buildings, the method which is universally employed is the distribution board system (*see* Fig. **55**).

In this system the mains are brought through the main fuses, meter, and double-pole switch to two bus-bars on the main distribution board (M.D.B.). From these bus-bars branch circuits are taken off through the double-pole fuses (F.F.). These branch circuits may go either direct to the lamps, as is the case with an ordinary medium-sized house or building, or to branch distribution or fuse-boards (B.D.B.), which in their turn supply the lamps. In the case of a very large building, there may be sub-distribution boards between the main distribution board and the branch distribution or fuse-boards. In accordance with I.E.E. Wiring Regulations, the maximum number of points * that

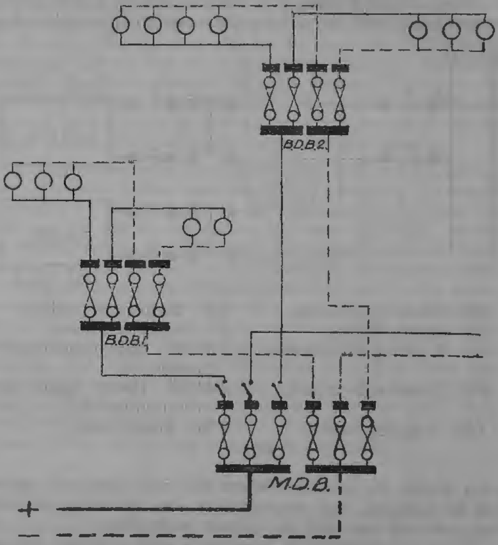


Fig. 55.

NOTE.—Lamp switches not shown.

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* A "*point*" is defined in the Regulations for Electrical Equipment of Buildings as "the termination of the wiring for attachment to a fitting for one or more lamps or other consuming devices." Thus the

may be connected in parallel to a final sub-circuit is as follows :—

> Where the total rating of the points supplied from the sub-circuit does not exceed—
>
> 6 amperes .. 10 points.
> 8 ,, .. 6 ,,
> 10 ,, .. 4 ,,
> 20 ,, .. 2 ,,
>
> Final sub-circuits supplying one lamp or appliance are not limited as to current-carrying capacity.

Each group of lamps is protected by double-pole fuses on its own distribution board, an arrangement which effectively meets the requirements of the I.E.E. Wiring Regulations for grouping and accessibility.

On large systems where there is more than one distribution board in series between the supply and the final sub-circuits, it is desirable that all except the final fuseboards be provided with single-pole switches on each way, as well as double-pole fuses as shown in Fig. 55.

3. **Tree system.**—In the early days of electric lighting the tree system was occasionally employed, and installations employing this system may possibly still be in use. It affords a useful object lesson in what to avoid. Fig. 56 indicates the lines upon which the system was designed.

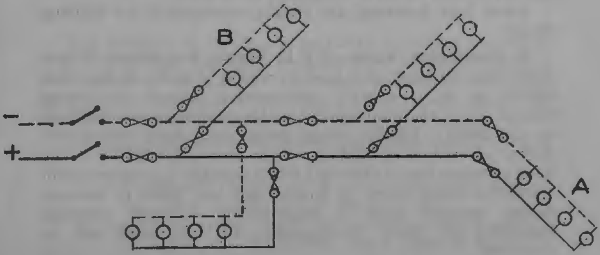

Fig. 56.

In the first place, there will be a greater voltage drop to the lamps at A than to the lamps at B, and, consequently,

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wiring of a ceiling rose controlled by one switch is one point, however many lamps are contained in the fitting supplied from the rose. But if there are two *switches* controlling one rose three wires must be led to the rose and the number of points is two. Single lamps are always one point each, though for costing purposes some engineers reckon a lamp controlled by two 2-way switches as 1½ points.

either the lamps at A will give a poor light or the lamps at B will be persistently over-volted.

Further, the requirements of the I.E.E. Wiring Regulations as regards the protection of branch circuits by double-pole fuses, the insertion of fuses wherever mains decrease in section, and the grouping and accessibility of fuses, can obviously only be met by the expenditure of a large amount of extra wire. In buildings which were wired on this system, the fuses were usually very scattered and often in most inaccessible positions, such as ceiling roses, and in consequence the isolation of the different branches for testing purposes or location of faults was a much more laborious proceeding than is the case with a distribution board system.

4. **Power circuits.**—Heating, cooking, and motor-driven apparatus, &c., must be connected to separate circuits entirely independent of the lighting circuits, and these have to comply with the same rules regarding the number of points on each circuit as are given in para. 2. They will almost invariably require a heavier conductor than the 3/0·029 usually used on lighting sub-circuits. Where supply is made by a supply company with separate tariffs for power and lighting a separate meter will have to be fixed.

Small fans, however, are usually connected to the lighting circuit.

5. **Conductor sizes.**—I.E.E. Wiring Regulation 72 lays down that no conductor used in wiring is to be of less than 0·0015 sq. in. (1/0·044″) cross-section, except for wiring fittings where the minimum allowable cross-section is 0·001 sq. in. (1/0·036″). Flexible cords, where used, must have a conductor of at least 0·0006 sq. in. in area (14/0·0076″). The most common size of cable is J 0·002 (3/0·029″), a three-strand conductor being easier to handle and less liable to damage during erection than a single-strand. Current carrying capacities are given in Appendix VI, and must not be exceeded.

Regulation 74 states that the fall in voltage from the consumer's terminals to the furthest point on the installation must not exceed 1 volt plus 3 per cent. of the declared voltage. In all ordinary cases, no calculations are necessary as J 0·002 is amply large enough, but the point should be watched with a large distribution system if there are many high-wattage lamps close together. It is possible that calculations may be necessary sometimes on heating and power circuits also—although the voltage drop is not limited to 1 volt plus 3 per cent., it is a good rule to work to.

6. **Balancing circuits.**—If possible, sub-circuits should be approximately the same length and should carry approxi-

mately the same currents. This greatly facilitates wiring, as only one size of conductor will then be used throughout, and only one size of fuse wire will be used in the distribution boards. This obviates the risk of using the wrong size of conductor in any circuit and also the wrong size of fuse wire.

7. Looping-in.—In the past it has been advocated that looping-in, as shown in Fig. 57, should be universally adopted when wiring.

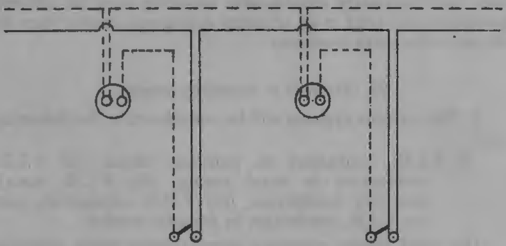


Fig. 57.

This method of wiring has certainly the great advantage of almost entirely excluding T-connections, which are a source of weakness *if badly made.* However, provided that proper connectors are employed and that a skilled man carries out the work, there is no reason why it should give trouble.

On the other hand, looping-in has many disadvantages, viz. :—

i. The difficulty of getting the loop into some fittings, *e.g.*, lamp holders, small brackets, &c.
ii. Increase in cost. Quite 50 per cent. of extra cable is required, and frequently larger sizes of materials for the installation are necessitated.
iii. A greater length of conductor ; hence a greater voltage drop and consequent waste of energy.
iv. The multiplicity of wires is confusing, especially in locating faults.
v. A greater risk of careless handling of the cable, resulting in decreased efficiency.
vi. Additions necessitate looping being discarded.
vii. Conduits (*see* Sec. **72**) more tightly packed and, therefore, less ventilated.

Indiscriminate looping is, therefore, not recommended, but it may be used with advantage in some circumstances, such as for a row of pendants or for a number of switches close together.

It should be noted that the bight of the conductors should *not* be cut, but that the conductor should be bared just sufficiently to make contact with the terminal of the switch, ceiling rose, &c.

Generally speaking, looping-in should not be employed wherever the cost of the extra wire entailed is as great as the cost of the connector. A connector may be used as a ceiling rose, and frequently considerable economy may be effected by making the joint in an adjacent ceiling rose rather than by the use of an extra connector.

72. *Methods of installing wiring.*

1. The various systems will be considered in the following order :—

(i) V.I.R. conductors on porcelain cleats, (ii) V.I.R. conductors in wood casing, (iii) V.I.R. metal-sheathed conductors, (iv) T.R.S. conductors, and (v) V.I.R. conductors in metallic conduit.

The chief points requiring consideration when selecting a wiring system for peace conditions are, in order of importance :—

- i. *Safety*, *i.e.*, the degree to which it reduces the possibility of poor workmanship producing dangerous results from shock and fire.
- ii. *Durability*, *i.e.*, ability to withstand fair wear and tear and, in addition, any peculiar conditions which may appertain in the place of installation. No one system of wiring is the best for all conditions.
- iii. *Appearance.*
- iv. *Initial Cost*, including in old houses cost of making good subsequent to installation.
- v. *Accessibility* of the installation from the point of view of renewals and extensions.

Bonding, earthing, and condensation must also be considered when selecting the system. In metal covered systems, contact between a live wire and the metal introduces risk of shock and fire. As modern systems of A.C. supply for lighting are generally at 230 volts (maximum value 326 volts) the danger is very real in situations at all damp, particularly in bathrooms, garages, stables, laundries, and similar buildings. The risks are generally lessened if the metal cover is effectively bonded throughout its length and definitely connected to earth (*see* Sec. 74).

As regards condensation, it is generally considered that

CLEAT WIRING.

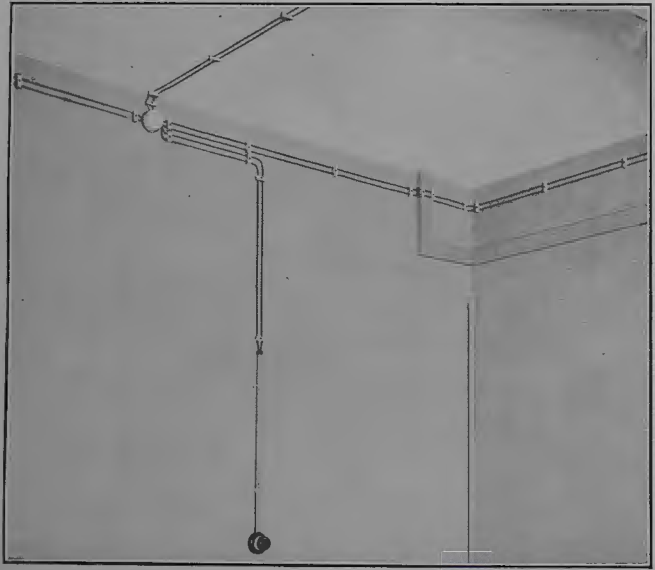


Fig. 1.

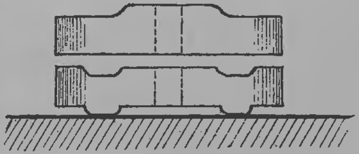


Fig. 2.

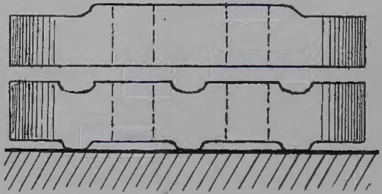


Fig. 3.

PLATE 104.

a screwed conduit system is watertight, but it is not airtight unless it is hermetically sealed. As this is not practicable for general purposes, the " breathing " which goes on, due to changes in temperature, results in the entry of moisture, which rusts away the interior of the tubes and in time destroys the insulating properties of the rubber. This destructive effect is accelerated in D.C. systems because of electric osmosis—the property of electric currents of forcing moisture through to the negative conductor. Precautions for minimizing condensation are given in para. 6.

2. **Cleat wiring.**—This is one of the cheapest methods of securing the conductors. The wires are supported in porcelain cleats, such as are shown on Pl. **104**, Figs. 2 and 3. The cleat is made in two halves, the inside of one half being grooved to take the leads. The whole is screwed to the wall, and the conductors are thus firmly gripped between the two halves of the cleat.

This system is only permitted if the wires are exposed to view. It is generally unsuitable and is not permitted for permanent work in barracks. It has been used extensively in India and the Colonies, particularly where condensation troubles preclude the use of conduit.

The system is very cheap, easily and quickly installed, the wires are always visible and easily inspected, alterations and additions are easy to make, and recovery of the stores is practicable when the installation is no longer required. The system is therefore eminently suitable for temporary surface work.

The real objections for barrack rooms and quarters are that although the wires can be made to look fairly neat on first erection, after a time they present a very ragged appearance; they sag in places and collect dust, and become disarranged by repainting and distempering; and, moreover, the lime in the distemper rots the insulation, penetrates to the copper conductor which corrodes and eventually breaks. Moreover, as the wires are not flush with the surface there is a temptation to hang Xmas decorations, articles of equipment, &c., from them, and this alone leads to endless trouble and maintenance costs.

The reduction of the cleat spacing to one foot overcomes many of these difficulties, but at the same time considerably increases the cost. The system must not be used in blacksmiths' or similar shops, as oil and smoke are very deleterious to V.I.R. cables.

Cleats are made in three forms so as to take one, two, or three conductors, and are known as single-groove, double-groove, and treble-groove respectively. The following are the most important points to be observed in the installation of wiring on this system :—

i. Wires must be stretched taut between cleats, in order not to touch walls, &c.

ii. The proper form of cleat must always be used, *e.g.*, double-grooved cleats must not be used for a single conductor.

iii. Cleats must not be more than 3 feet apart, horizontally or vertically.

iv. The spacing of cleats round bends or projections must be so reduced that the conductors are never less than the thickness of a half-cleat away from such a bend or projection.

v. The wires must be enclosed in steel conduit or wood casing from within 6 feet above any floor to 4 inches below the floor. After lengths of conduits have been cut, the ends must be well reamered out to prevent damage to the wires when drawing-in, and bushes must be provided for all ends except those butting into a wooden block. According to the I.E.E. Wiring Regulations, such isolated lengths of conduit need not be earthed except in special cases (*see* Sec. **74**).

vi. Where wires enter a length of conduit, a cleat must be placed close to the end of the conduit. Similarly, where wires enter a fitting, there must be a cleat close up on either side thereof.

vii. Where runs of cleated work cross or are superimposed, such a number of half-cleats must be employed as will maintain a rigid separation of the wires of not less than ½ inch.

viii. Where wires pass through walls, floors, or any other brickwork, masonry, or woodwork, they must be protected by some form of approved tubing.

ix. Where it is uneconomical to employ looping-in (*see* Sec. **71**), connectors should be used for branchings in conjunction with plain wooden blocks.

x. The wires must be kept away from gas and water pipes and structural metal work.

Special types of grooved fittings are made for wiring by the cleat method, and these should invariably be used in conjunction with plain wooden blocks.

Pl. **104**, Fig. 1, shows an illustration of a section of wiring on cleats.

3. **Wood casing.**—This method has been used extensively in the past, and is still considerably used abroad where cheap skilled labour is available. The wires are laid in grooves in a

rectangular piece of wood called the " troughing," and covered by a rectangular strip of wood the same breadth as the troughing and secured to it by screws; this is called the capping. A double bead is cut in the capping to indicate the position of the wires, so that screws shall not be driven through in the wrong places and damage the wires. Wires of the same polarity may be bunched, *i.e.*, two or more may be placed in one groove, but the bunching of conductors of opposite polarity in wood casing should be avoided.

Two main causes are responsible for this system falling into disuse :—

i. The fire risk.
ii. The fact that highly skilled carpenters are necessary to make a neat job of the casing; these, even if obtainable, commanding high wages.

A typical section of casing is shown on Pl. **105**, Figs. 1 and 2.

In installing casing, the following points should be noted :—

i. The timber (usually American white wood, though oak or walnut may be used to harmonize with surroundings) should be thoroughly seasoned, in order to avoid warping and cracking. Teak should be used in the tropics, to minimize trouble due to white ants.
ii. Measurements should be carefully taken, in order to avoid gaps.
iii. The casing should be firmly secured, and no part of it should be supported by the conductors.
iv. The casing should not be buried in plaster, brickwork, or masonry, though it may be countersunk so that the capping is flush with the surface.
v. In passing through brickwork or masonry the cables should be carried in approved tubing. Joints between tubing and casing should be made by special connectors, or the tubing should be butted into the casing.
vi. At bends, the corners of the grooves should be carefully rounded off to prevent damage to the insulation of the wires.
vii. Branching can conveniently be accomplished by means of looping, though there is no serious objection to the use of T-joints, provided that a skilled jointer is employed to carry out the work. It will usually, however, be economical to employ connectors for all but very short loops, as with other forms of wiring.

Plate 105.

WOOD CASING AND STEEL CONDUIT.

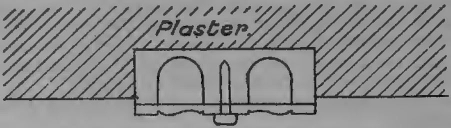


Fig. 1. Section of Casing.

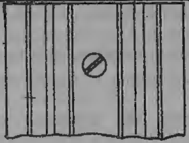


Fig. 2. Elevation of casing.

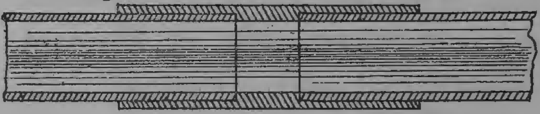


Fig. 3. Conduit. Slip socket joint.

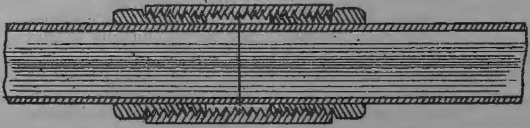


Fig. 4. Conduit. Screwed socket joint

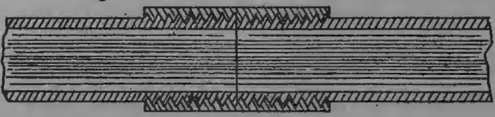


Fig. 5. Conduit. Screwed joint.

PLATE 106.

WIRING. (Methods of Fixing.)

Metal clip.

Lead strip.

Fibre Bracket. (Can be obtained to secure any number of wires.)

T.R.S. WIRING.

4. Tough rubber-sheathed wiring.—T.R.S. (cab-tyre sheathed, *see* Chap. V, Sec. **38**) cables are particularly suitable for house wiring, and can be used with standard fittings. Single, twin, either circular or oval, and three-core cables are all standard productions in all the usual grades.

T.R.S. cable needs no further protection, and can be run inconspicuously on the surface of walls or buried in plaster without deterioration, and also is allowed by the I.E.E. Regulations to be run between floors and ceilings and in hollow walls.

There being no metal covering, the questions of bonding and earthing need not be considered, and of course internal condensation cannot occur. T.R.S. cable is said to be unaffected by paint, lime and colour washes, and acid fumes, but has only been in use for about fifteen years, so that the limit of its useful life is not yet definitely established.

The twin cable is no cheaper than two single cables; it is difficult to run neatly and, particularly abroad, has a habit of shorting inside the outer sheath. When wiring connectors and fittings the outer sheath has to be removed. For these various reasons it is better to use single cables only for all purposes.

Various methods of securing T.R.S. cable are shown in Pl. **106.** Porcelain, fibre or metal cleats, may be used; fibre or metal clips or saddles, lead alloy strips (pure lead is too soft) cut to length, or special staples. Fastenings with one fixing screw on one side of the cable only do not make a very neat job. Fixing by cleats is only necessary when it is desired to space the cable from the wall. The most satisfactory methods of fastening are metal clips or lead alloy strips, metal clips having the advantage that only one screw is necessary, and only one hole has to be drilled and plugged in the wall.

T.R.S. wiring requires a good deal of care in erection, if it is to have a permanently neat appearance, as it is less rigid and more difficult to run in straight lines than the metal-sheathed systems. It should be fastened at intervals of not more than a foot.

Extruded cables.—A special type of cable has been introduced by certain manufacturers, in which the insulation is in one layer only of tough rubber. Twin and triple cables in some cases consist of single cables joined by webs, through which nails may be driven for fixing purposes. These cables have trade names ending in "ite," *e.g.*, Maconite, Virite. Many advantages are claimed, but there is no evidence that they are actually superior to ordinary T.R.S. cables, and they will not, as a rule, stand up to the same mechanical and electrical tests as required by the G.D.E.S. for T.R.S. cables.

These extruded cables have been said to have better lasting qualities in the tropics, but it is considered that ordinary T.R.S. cables are quite as good, and, if necessary, the layer of pure rubber next to the conductor may be replaced by a layer of V.I.R.

The use of these extruded cables, except for replacements, has temporarily been forbidden for W.D. work.

These cables can be used alone in the same way as ordinary T.R.S.; fixed straight to the wall with a thin wood beading over it; or in channelling. In all cases wooden or composition cover pieces are necessary at right-angle bends, as the twin and triple cables will not bend neatly through a right angle in their own plane. Care should be taken when screwing these bends up, as they are very brittle. Beading is unsightly and weak, and should not be used. Channelling should be fastened with spring clips, and not with screws through the casing. Where a dead end in the channelling occurs the run can be neatly finished off by a wood block.

Pl. **107** shows an illustration of a section of T.R.S. wiring.

The following special points must be watched in T.R.S. installations:—

(1) If the wiring is concealed in plaster a layer of neat cement should be run on top to prevent damage from nails.

(2) In damp places special measures must be taken to earth switches, lampholders, and the metal work of portable fittings.

(3) The sheath must not be under stress in any way when erected, either as result of pressure from a cleat, or from sharp bends.

(4) With bad walls a teak fillet may be used to which the cables are fastened.

(5) Fibre clips, being hygroscopic, must not be used in exterior work, or in damp places.

(6) In damp situations the ends of T.R.S. Cables must be sealed with Chatterton's Compound.

5. **Metal sheathed wiring.**—Wiring systems using rubber insulated cables with an outer sheath of lead alloy containing at least 95 per cent. pure lead are used to a large extent at the present time in domestic work, and in churches and similar buildings. The cables are smaller than T.R.S. and can be run very unobtrusively on surfaces without damaging decorations. The metal sheath must be bonded and earthed throughout, as if this is not done it is readily attacked by electrolytic action due to leakage currents. To ensure efficient bonding each cable manufacturer markets a complete wiring system of cable, boxes, clamps, etc., which are not interchangeable with apparatus of other makes.

These systems are fairly cheap in first cost, but to be safe need skilled erection by labour experienced in the particular system in use. The only guarantee of the quality of the cable is the reputation of the manufacturer (as C.M.A. Grades are not normally stocked), and the life of an installation rests entirely on the lead sheath, which is liable to pinhole faults difficult to detect, and to attacks by vermin.

Metal sheathed wiring systems are not recommended for military purposes. Should circumstances necessitate their use the following are among the most important points to be noticed in installation :—

i. The metal sheathing must be earthed (*see* Sec. **74**), and made electrically continuous throughout by means of wiped joints, bonding clamps, or special boxes, which incorporate bonding clamps.

ii. The cable should be supported by the proper clips, saddles, &c., at intervals of not more than 3 feet on both horizontal and vertical runs. The supports must be of a material not liable to set up chemical action with the sheath, and must have no sharp edges.

iii. Change of direction should be made over a rounded support of diameter not less than twelve times the external diameter of the sheathing.

iv. The cable should not be allowed to come in contact with damp plaster, brickwork, or unpainted wood, particularly oak.

v. The cable should be protected by conduit or wood casing wherever it is liable to mechanical injury. Where it is buried, it should be enclosed in metal conduit.

vi. Where it is uneconomical to employ looping-in (*see* Sec. **71**), branchings may be made by the insertion of *connectors, porcelain* in the special junction boxes provided for the system in use, or the work may be done and electrical continuity assured by the use of connectors and bonding blocks.

vii. Holes in steel and iron work, through which these cables pass, must be bushed to prevent abrasion, and the cables must be kept away from gas and waterpipes.

NOTE.—*No contracts, &c., exist for the supply of the special stores required for these systems, and local arrangements will have to be made for their purchase.*

6. **Metallic conduit wiring.**—Undoubtedly the best wiring system where mechanical protection against accident or malicious damage is an important consideration, such as in public and most military buildings, workshops, large

offices, and the like, is V.I.R. cables in metal (usually steel) conduit. This system also indisputably affords the best protection from shock and fire if the bonding and earthing are well done.

There are two main classes of metal conduit, viz., light gauge and heavy gauge. Although all forms of conduit may be obtained in both gauges, it may be stated that the former class generally includes *close-joint*, or *open-seam, tubing* and *brazed tubing*, and the latter class *solid-drawn seamless* or *welded tubing*. Heavy gauge tubing only is permitted in permanent W.D. installations.

The *close-joint* or *open-seam tubing* is the cheapest form of conduit, and is made by bending steel strips into a cylindrical form. The two edges are simply made to butt closely together without any metallic junction. The tube is either galvanized or enamelled inside and out, the latter process assisting the insulation of the cable. This form of conduit is not recommended for good work; its chief use is a mechancial protection for cleat or T.R.S. wiring (*q.v.*). It has the advantage over such systems as wood casing, &c., of being a better protection both mechanically and against fire.

Two forms of joint may be employed for this conduit.

The first, known as the slip socket, is as shown on Pl. **105**, Fig. 3. Both tubes are inserted into a plain socket which is constructed with shoulders against which the tubes butt. It is a cheap form of joint and is easily and quickly made, *but does not comply with I.E.E. Wiring Regulations*, owing to the difficulty of ensuring electrical and mechanical continuity.

Among the best of the improved systems employing light gauge conduit with slip socket joints is the "Terra-grip," in which the couplers and the outlets of fittings are provided with screw studs. This is a cheap and quickly erected system.

The second form, known as the screwed socket, is shown on Pl. **105**, Fig. 4. It consists of a socket into which are screwed two split screwed bushes which grip the ends of the conduit.

In the *brazed tubing* form of conduit the two edges of the strip are *brazed* together, thus rendering it possible to make the installation damp proof. In other respects it is similar to open seam tubing, but has the grave disadvantage that pieces of spelter are frequently left projecting inside the tube, to the detriment of the wire, during drawing-in particularly.

Seamless conduit is made from solid-drawn seamless tubing and is the most expensive variety. It is generally used for the best class of work, but welded tubing is cheaper and almost equally good.

The form of joint employed is as shown on Pl. **105**, Fig. 5. Both ends of the tubing are screwed; two pieces of tubing are joined by a screw socket or coupler in such a way that the ends of the conduit butt closely together. This form of joint ensures electrical and mechanical continuity, but it cannot be employed with close-joint or *brazed* tubing, owing to the impossibility of screwing these forms of tubing.

Heavy gauge screwed conduit, welded or solid drawn, should invariably be specified (*see* Regs. for R.E. Services, Pt. II, para. 4). B.S.S. 31 applies to all classes of conduit.

In civil practice, enamelled conduit is most commonly used, except in damp situations. For W.D. installations galvanized conduit should almost invariably be used, except where the extra cost of galvanizing over enamelling is not considered justified.

Fixing of conduit.—Conduit is secured by means of saddles, clips, or pipe hooks; the first method is most commonly employed in indoor wiring. Pipe hooks may be conveniently used where space does not permit the use of saddles. For cases where it is required to fix conduit to girders, special girder clips may be used. In this connection, it should be noted that, if the girder already carries a lead gas-pipe, the conduit must be insulated from the girder by means of wooden blocks.

Conduit accessories.—A large number of accessories, such as bends, junctions, boxes, &c., are necessary with a conduit system. A complete list of these can be obtained from D.W. Circulars or makers' catalogues. They should be made of malleable cast-iron, and with outlets for conduit at the back, at the sides, or tangentially. Boxes can be obtained circular or square, with fibre or metal covers. All switches, &c., should be mounted in or on boxes; where concealed wiring is used, the neatest arrangement is to use sunk switches (*see* Sec. **67**). Bends may be obtained with or without inspection covers; at 90° angles, the latter type should be used.

The *earthing of conduit* is dealt with in Sec. **74.**

Wiring capacity of conduit.—The I.E.E. Regulations and most conduit catalogues give tables showing how many wires of a given size any conduit will take. A ¾-inch conduit will take four 3/0·029 or 3/0·036 wires and a 1-inch conduit will take eight.

Where the circuit contains many bends and angles, these figures should be reduced to three and six respectively.

Wiring conduit.—There are three methods of wiring conduit, known as *threading-through*, *drawing-in*, and *pushing*. The last-named method is seldom used. As its name implies, the conduit is erected first and the wires are pushed through afterwards. This can only be done through straight lengths of not more than a few feet.

In the first-named method the wires are threaded through the conduit before erection, which is a slow and somewhat laborious process. Its principal use is when making small extensions to an existing installation.

Drawing-in is the method generally employed. The whole of the conduit, &c., is erected, and then fish wires are inserted and the wires are pulled through by means of the fish wires.

To facilitate the process the wires may be rubbed with French chalk as they go into the conduit, but this should never be necessary unless the number of wires in the conduit is excessive. Inspection bends and boxes for use when drawing-in are necessary at frequent intervals; it is not advisable to attempt to draw wire round more than one bend.

When drawing-in, great care should be taken that the wires do not get twisted round one another, for not only would the capacity of the tubing be reduced thereby and the difficulty of drawing increased, but it would probably be impossible to withdraw *one* of the wires at some future date in the case of a fault occurring or some alteration becoming necessary.

Except in the very simplest installations, the order and scheme of drawing-in, *i.e.*, where to commence, selection of drawing points, how to deal with branches, &c., is a matter requiring considerable forethought. The work should not be undertaken in a haphazard manner.

If the current is alternating, conductors of opposite polarity *must* be bunched so that the sum of the currents through any particular length of tubing at any instant is zero. If this is not done, there is a tendency for the tubing to become heated, owing to the production of eddy currents. In view of the many changes from D.C. to A.C. that are taking place at the present time, it is advisable to bunch conductors even on D.C.

When installing wiring on a conduit system, particular attention must be paid to the following points :—

i. *Condensation.*—The principal objection to conduit, and one which precludes its use in many tropical countries, is the danger of internal condensation (*see* para. 1). This is most likely to cause trouble where there are pronounced changes in temperature. It is advantageous to support conduit, when run in the open, out from the wall on creosoted wood blocks, to allow free air circulation. A conduit system should be ventilated so as to promote free air circulation inside it. Long horizontal runs should be given a definite fall, and care taken to avoid pockets where condensed moisture may rest. Dips and switches may have small ventilating holes on their under surfaces (provided there is no vapour about), and exit holes should be made in the upper part of the system. This can be done conveniently by fixing an open outlet, such as a " T," at the highest part of the system. Vermin can be kept out by gauze covers. When there is a long vertical run from a basement through several floors it is advisable to block the conduit at ground level and ventilate the upper and lower parts of the system separately.

If conduit must be installed in situations where internal condensation is very bad, the conduit should be scientifically drained, and 2,500-megohm cable used.

ii. Tubing should be cut with a special fine-toothed hacksaw (32 teeth to the inch), and the ends thoroughly reamered out to remove burrs, which would otherwise tear the covering of the wires when drawn in.

iii. The tubing must be carefully cut to the correct length and threaded to screw well into the box. Oil used must be carefully wiped away, as it is injurious to rubber. The thread should be coated with aluminium paint, and not red lead, as the latter may act as an insulator.

iv. Tubing may be bent cold in a bending machine, the inside radius of the bend not being less than three inches. Solid elbows, " T " pieces, and 4-way pieces should not be used.

v. Wherever wires enter or leave tubing without a box, the ends of the tubing must be properly bushed. Use brass bushes instead of ebonite when leading-in to buildings from overhead lines.

vi. Where tubing is buried in plaster, it must be firmly secured to the wall behind to prevent brackets, switches, &c., becoming loose.

vii. Avoid contact with *metal work,* and keep as far away as possible from *gas-pipes* and *hot-water pipes* (*see* Sec. 74).

viii. If possible, all conduit, whether galvanized or not, should be well *painted* before being covered in.

ix. It is generally more economical to adhere to *one size of tubing* throughout a circuit, even if parts of the run have to be duplicated. However, if an increase in size is adopted, all short branches from that part of the circuit should also be of the increased size, regardless of the number of leads in those branches.

x. Remember that the tubing must be *electrically continuous* throughout and *efficiently connected to earth.*

7. There are two mechanical appliances which are of great

use to the wireman. One is the rotary screwdriver, and the other is a tool known as the *Rapper*, made by Messrs. Geipel, Ltd., Vulcan Works, Bermondsey Street, S.E.1. It is intended for making holes in brick or plaster for the accommodation of wall plugs, and consists of the usual drill to which a spring-loaded hammer-head gives several hundred blows a minute by the turning of a handle. Much time can be saved by the use of this tool and a neater hole made than by drill or chisel and hammer.

73. *Comparison of methods of wiring.*

1. No hard-and-fast rules on the best wiring system can be laid down, and the engineer responsible for an installation must decide on the individual circumstances of each case. The following notes and comparative table of advantages and disadvantages may be of assistance :—

	Cleat.	Wood casing.	T.R.S.	Metal sheathed.	Screwed conduit.
Cost ..		*See* Sec. **86**	and Table	**N.**	
Life ..	Short.	Fairly long if undisturbed.	Long.	Long.	Very long if carefully installed.
Mechanical protection.	None.	Fair.	Good.	Poor.	Very good.
Fire ..	None.	Bad.	Fire resisting.	Fair.	Very good.
Damp ..	None.	Slight protection.	Good protection.	Good protection.	Poor.
Labour required.	Semi-skilled.	Highly skilled.	Skilled.	Skilled.	Very skilled.
Renewals and extensions.	Very easy.	Very difficult.	Easy.	Easy.	Difficult.
Time of installation.			*See* Sec. **86**.		
General reliability.	Poor.	Good.	Good.	Fairly good.	Very good.
Amount of making good necessary.	Little.	Little.	Little.	Little.	A great deal if concealed.

2. The disadvantages of conduit in small houses and quarters, apart from the care required in bonding and earthing, are its unsightliness on the surface and its bulk when concealed. Not less than ⅜ inch of plaster cover must be allowed on enamelled conduit if rusting through is to be avoided, but if galvanized conduit is used, it need only be just covered. Galvanized oval conduit takes up the least possible depth in the wall. The cost of conduit wiring is considerably less in a new building in course of erection than in an old one. For steel frame buildings it is generally possible to fasten the conduit to beams a good way apart and so save considerably in first cost.

There is always the possibility with conduit systems of a careless workman stripping the insulation off the conductors when drawing in and the damage not being discovered till a breakdown occurs.

T.R.S. wiring has a good deal to commend it for service requirements in all parts of the world. Owing to the high cost of the cable (about one and a half times as much as V.I.R.) and the large amount of plugging necessary, the cost per point is only about 20 per cent. less than for screwed conduit. Maconite is neater than ordinary T.R.S.

3. **Wiring in the tropics.**—In the tropics the moist heat and the condensation are particularly harmful to rubber-insulated cables. V.I.R. braided wire is not permitted in some places. Where it is used, it should comply with the appropriate G.D.E.S., *but with the layer of pure rubber replaced by vulcanized rubber.*

A somewhat similar commercial pattern cable is procurable under the trade name of "*Vicma,*" but cables ordered under the G.D.E.S. will usually pass more severe tests, and are not more expensive. Ordinary T.R.S. cable is probably nearly, if not quite, as good, and may be strongly recommended for use in stations abroad.

74. *Earthing and care of installation.*

1. Where the wires are enclosed in a metal tubing or metal sheathing, precautions must be taken to guard against accidents caused by the metal tubing or metal sheathing becoming *live.* These precautions include :—

i. Efficient bonding and earthing of the metal tubing or sheathing.
ii. Periodical testing and inspection of wiring and fittings to ensure that their insulation resistance is satisfactory.

Most supply systems have earthed neutrals, and when a fault occurs in the wiring there is a heavy rush of current which will not be confined to the earth wire if the conduit is in contact with metal work (such as iron girders, bell wires, gas-pipes, &c.), and if the leakage reaches any block tin gas-pipe, the chances are that the tin is burnt through and the gas lit. It is therefore desirable to keep conduit from contact with all metal work in buildings. Fibre shields and wood bridges are aids to this end. Moreover, when the conduit is moderately insulated from earth everywhere except at the definite earth connections, it is always possible to test its continuity and its freedom from contact with other metal.

This is admittedly a counsel of perfection which it may not always be practicable to realize in extensive installations in steel frame buildings, and the I.E.E. Regulations permit the conduit to be in metallic contact with the steelwork *if the latter is itself earthed*.

In this connection the following extract from the memorandum on the H.O. Regulations for Factories and Workshops should be carefully noted:—

"For installations in steel-frame buildings the framework of the building has sometimes been utilized as an earth connection instead of earth plates. This method cannot, however, be relied upon without special investigation, even where the number of metal columns entering the ground is large. The columns generally rest on concrete foundations, not always below the surface of the ground. Even where they do enter the ground it may be for a few inches only, and they may be practically insulated therefrom by paint, and the ground itself may be dry. Cases have arisen where, when leakage has occurred, the whole building has been charged up to a dangerous voltage, leading to serious accidents, in one instance to fatal shock."

2. **Earthing and bonding.**—As regards (i), care should be taken that the earth resistance is sufficiently low to prevent a dangerous difference of potential between the live tubing and earth. In the case of A.C. systems, it is also necessary to avoid undue inductance in the earth connection, and this can best be effected by arranging for the earthing wire to be as short and direct as possible; it may necessitate a larger number of earth connections than would be required from the point of view of ohmic resistance alone.

Water mains usually afford a very efficient earth, but it is important to make certain that no difference of potential can exist between the water and the containing pipe, a state of affairs which may be caused by a deposit in the pipe or by a non-conducting compound applied inside the pipe. The importance of this particular point is greater in a dry locality than in a wet one.

Gas-pipes must on no account be employed to obtain an earth. Down-drain pipes should also be avoided, since, even when the pipes enter the ground, they are only taken a few inches below the surface, the drains being continued by earthenware pipes.

Where an efficient earth or earths cannot otherwise be obtained, ***earth plates***, **18** inches square, should be buried in the ground, preferably in an upright position, and surrounded by about 12 inches of broken coke, free from sulphur. The place selected should be permanently wet or at least damp.

Precautions to be taken to ensure efficient bonding in conduit and metal sheathing are stressed in Sec. **72** when dealing with those systems.

Earthing of fittings, &c.—I.E.E. Regulation No. 96 states that exposed metal liable to become alive in the event of insulation becoming defective shall be earthed in bathrooms, lift shafts, the immediate neighbourhood of machinery, and all places where a slight shock may lead to serious accident.

In steel-framed buildings the framework should be effectively earthed, and any metal work coming under this regulation, connected to it.

In addition, metal work in bathrooms coming under the above regulation must be placed out of reach of a person standing in the bath, and lampholders must be earthed or made of insulating material.

In other situations it is not considered absolutely necessary to earth metal portable fittings, switches, &c., but it is very desirable in all damp places, such as kitchens, sculleries, and laundries, to earth appliances such as kettles and irons. With T.R.S. or cleat wiring, earthing is somewhat difficult; a wire from the plug to the nearest cold-water pipe being the only solution. The following measures are recommended, though some are only applicable to metal-clad systems :—

Switches.—In slightly damp situations, use switches with covers and dollies of insulating material. In very damp places, where this precaution is insufficient, use ironclad switches, or, where these are considered too ugly, switches with dollies and covers earthed to the box by the fixing screw.

Portable fittings.—Use three-pin wall sockets and plugs, and three-core flex (armour clad if liable to damage), with the armouring connected to earth. Connect the third core to the conduit at the wall socket and the metal at the fitting. Keep flexible wires as short as possible.

Lampholders.—Use a three-core flex as for fittings, or, for preference, Home Office pattern lampholders (*see* Sec. **66**).

Hand inspection lamps.—Use the Home Office type, in which the lampholder is encased in a non-metallic frame, and the metal guard, if used, is so fitted that it cannot touch the lampholder. For use in the neighbourhood of bare electrical conductors, the whole lamp exterior must be non-metallic. Hand inspection lamps must have efficient cord grips, and a leather loop for hanging up is preferable to a metallic hook, as the latter may in time cut through the insulation of the flexible cord.

It may be noted here that in supply systems which work normally with one pole earthed, the insulation of the earthed conductor must be maintained throughout, the earth connection being made at one point only, viz. the power station or sub-station. It is therefore not permissible to connect the metal work of portable fittings to the earthed conductor.

Earthing conductors must be of copper of a cross-sectional area not less than one-half of the largest conductor to be protected, provided that it is at least 7/0·029 inches, and need not be larger than 0·1 sq. inch. Where the cross-sectional area of portable or other leads is 0·0048 sq. inch or smaller, the earthing conductor shall be equal in area to the live conductor. The earth wires must be suitably protected from mechanical injury.

The importance of these precautions varies directly with the voltage employed, and it should be remembered that any voltage above 100 volts A.C. may be **dangerous to life,** and that the danger is greater, at a given voltage, with A.C. than with D.C. systems.

Special care is necessary abroad and in stables, since dark-skinned peoples and horses are peculiarly susceptible to shock.

3. **Testing** (R.E.S., Part II, 1928, para. 26). No installation or alteration or extension of an installation should be considered complete nor the current switched on until the insulation resistance has been tested in accordance with the I.E.E. Wiring Regulations, and it should not be pronounced satisfactory unless the requirements of these rules have been met. Similarly, no existing plant should be taken over without a thorough test of the insulation resistance being made.

In addition, *triennial tests* should be made at the main or house-service fuses to ascertain whether the condition of installations in all permanent buildings is satisfactory. Similar tests should be carried out *annually* in all temporary encampments and buildings.

Records should be kept of all tests, so that any gradual deterioration of plant may be detected.

The 500V megger or similar apparatus should be used.

The I.E.E. Wiring Regulations regarding testing are as follows, and it should be noted that these rules apply whatever system of wiring may be employed :—

Testing of completed installation.

NOTE.—The following tests are intended to ensure that the installation is in a satisfactory state at the time of completion. The value of systematically inspecting and testing apparatus and circuits cannot be too strongly urged, and such periodical tests are essential if the installation is to be maintained in a sound condition and undue deterioration thereof detected. All defects thus discovered should be made good without loss of time. The attention of consumers should be drawn to the importance of maintaining all apparatus and fittings in a clean and dry condition.

127. Requirements to be complied with :—

Before an installation is permanently put into service, it shall comply with the demands of the following tests :—

A. *Insulation Resistance.*

(*a*) The insulation resistance shall be measured by applying between earth and the whole system of conductors or any section thereof, with all fuses in place and all switches on, a direct-current voltage of not less than twice the working voltage. Where the supply is derived from a three-wire (alternating or direct current) or polyphase system, the neutral of which is connected to earth either direct or through added resistance, the working voltage shall be deemed to be that which is maintained between the outer or phase conductors and the neutral.

(*b*) The insulation resistance of an installation measured as in (*a*) above shall not be less in megohms than 25 divided by the number of points on the circuits, provided that :—

- (i) Any installation shall not be required to have an insulation resistance greater than 1 megohm.
- (ii) Lighting circuits shall be tested with all lamps in place, except in the case of earthed concentric wiring systems.
- (iii) Heating and power circuits, with or without lighting points, may be tested, if desired, with the heating and power appliances disconnected from the circuits, but with the lamps (if any) in place.
- (iv) The insulation resistance between the case or framework and every live part of each individual dynamo, motor, heater, arc lamp, control gear, or other appliance shall not be less than that specified in the appropriate British Standard Specification or, where there is no such specification, shall not be less than half a megohm.

NOTE.—In addition to the foregoing tests it is advisable, wherever practicable, to take an insulation test between all the conductors connected to one pole or phase and all the conductors connected to the other pole or phase of a system.

B. *Continuity of Metal Sheathing.*

The metal conduits or metallic envelopes of cables in all cases where such methods are used for the mechanical protection of electrical conductors shall be tested for electrical continuity, and the electrical resistance of such conduits or sheathing, measured between a point near the main switch and any other point of the completed installation, shall not exceed 2 ohms.

The most likely cause of any failure to pass these tests will be dampness at the ends of cables, and in wall sockets, switches, &c., if these are made of porcelain, which is very hygroscopic.

Except in the initial tests carried out on completion of the wiring of an installation or an alteration or an extension, there is no need to test the sub-circuits in detail, unless the test of the complete installation is unsatisfactory.

Concurrently with the periodical tests, a visual inspection should be made of all flexible leads, wall plugs, portable fittings, &c., to ascertain that they are in good working condition and that circuits are not overloaded.

At these inspections also it should be ascertained that no unauthorized appliances are installed.

Small electric appliances such as irons and vacuum cleaners are now permitted in married quarters if the supply is separately metered (*see* para. 108, R.E.S., Part I, 1930).

4. **Fuses and lamps**.—Serious defects which have occurred in internal wiring systems have been attributed to the use of badly-proportioned sub-circuit fuses, to the use of lamps of incorrect pressure, or to the replacement of such fuses or lamps by unauthorized and unskilled persons.

The use of fuses of incorrect proportions involves a risk of fire, which is considerable, particularly in the case of huts and other buildings where cleat wiring is employed.

The following procedure should, therefore, be adopted in all cases :—

- i. The system of fusing should be examined where there is any doubt as to its efficiency, and in cases where any serious departure from the I.E.E. Wiring Regulations is observed, the fault should be remedied.
- ii. Covers should be fitted to all fuses and fuse-boards, and these covers should be so secured, by seals or otherwise, as to ensure that they cannot be tampered with by unauthorized persons.
- iii. A fuse wire should never be replaced by one of heavier gauge or different metal, except under the orders of some competent authority.
- iv. Frequent and careful inspections of the fuses should be made.
- v. Care should be taken that only lamps of the correct voltage are used. No lamps should be used whose marked voltage is more than 5 per cent. below the supply voltage.

5. The following I.E.E. Regulations have not been mentioned elsewhere, but are of importance :—

Regulations	79 and 87 (*z*)	Types and conditions of use of flexible cords.
,,	88	Earthed concentric wiring.
,,	94	Control of supply.
,,	106	Portable fittings.
,,	111	Every lampholder adaptor must be controlled by a switch in a convenient position, and must not be used for currents of over 2 amperes.
,,	112	Wall plugs and sockets.
,,	123–125	Heating and cooking appliances.

75. *Switching.*

1. The thoughtful selection of switch positions and subdivision of the control of the lamps will frequently be the main factor towards the success of an installation. Not only will the convenience of the occupants be considerably enhanced, but it will also be possible to reduce appreciably the current consumption. Moreover, the judicious selection of switch positions will in some cases facilitate the lay-out of the wiring.

It should hardly be necessary to state that there should always be a switch conveniently at hand when entering a room, but it is not always recognized that it is advisable to extend this principle for rooms possessing more than one point of entry. In cases where there is no suitable position close to the door, it may be convenient to place the switch outside.

It is usually uneconomical in the long run to use one switch for controlling a number of lamps which are situated at different points, for it rarely happens that all the lamps will always be required at the same time. A single fitting containing 2 or more lamps does not usually need a switch for each lamp, though it will often be useful to provide 2 switches for a 3-lamp fitting, so that three degrees of illumination (one, two, or three lamps) may be obtainable (*see* Fig. 58).

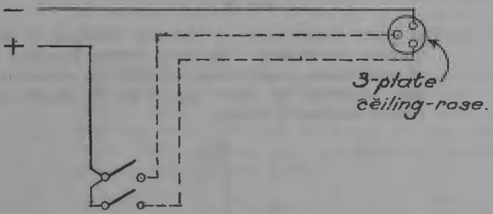


Fig. 58.

Local lights (*see* Sec. **63**) should normally be provided with separate control near at hand, *e.g.*, switch lampholders with a push-pull, and not a rotary pattern switch, or ceiling switches (*see* Sec. **67**).

2. It is not possible to deal fully with all the different types of switches obtainable and their multitudinous uses; but examples of some of the more common possibilities are appended :—

i. Fig. 59 shows how unintentional waste may be avoided when one room leads out of another, *e.g.*, a small store from a main store or a larder from a scullery.

Sw. 1 acts as a master-switch control over the switch and lamp of the inner room, and the possibility of leaving the inner room light on will be greatly reduced.

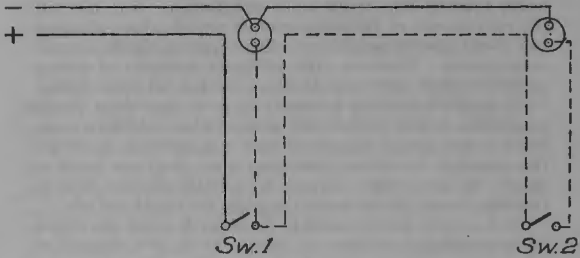
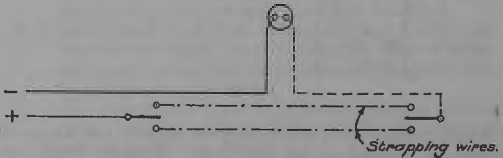


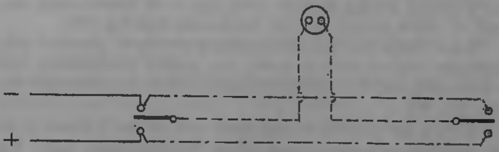
Fig. 59.

ii. The great convenience of two-way switches is frequently overlooked. The extra wiring involved is of small consequence compared with the extra comfort bestowed by their use. Fig. 60 shows the correct method of wiring.



Correct.

Fig. 60.

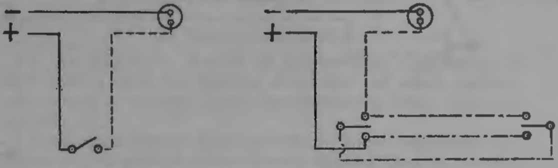


Incorrect.

Fig. 61.

It is undesirable to wire so that both positive and negative mains are brought to each of the two-way switches, as shown in Fig. 61.

When it is desired to provide alternative control from a second point for a light which has control from one point only, with the minimum of disturbance to the existing wiring, the method indicated in Fig. 62 is recommended.



Before alteration. *After alteration.*

Fig. 62.

It will be noticed that, apart from the provision of two-way switches, it is merely necessary to run three wires from the existing control position to the proposed alternative position.

Alternative control is invaluable for staircase lighting and for long corridors and passages ; it may be useful in rooms which have two doors and may also be utilized with advantage in many other rooms, such as offices (*e.g.*, one switch at the door and one switch on the desk).

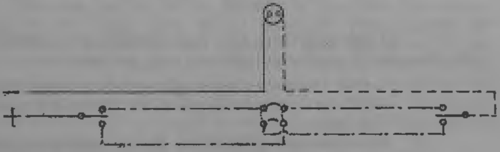


Fig. 63.

iii. Control from more than two points can easily be arranged by the introduction of one or more intermediate switches, as shown in Fig. 63.

Such may be necessary on certain types of staircases, in very long passages, &c.

iv. Fig. 64 shows how control for two lamps from one point may be arranged so that only one light at a time can be on.

One ordinary single-way and one two-way switch are required, or a two-way switch with an off position may be used.

v. Fig. 65 shows how control for two lamps in one room from either of two points may be arranged so that only one lamp at a time can be on.

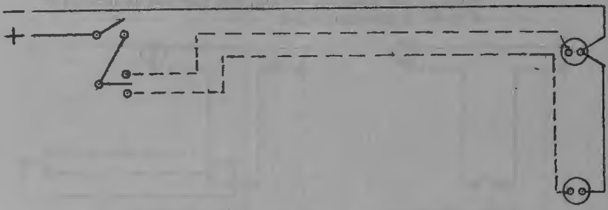


Fig. 64.

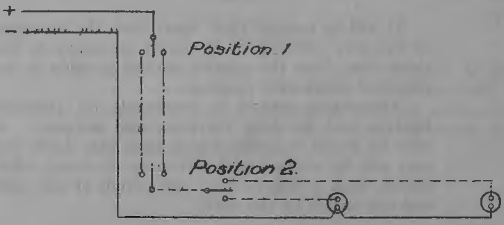


Fig. 65.

In this case three two-way switches are required.

vi. Amongst the other possibilities may be mentioned:—

(a) *Twinob* switches (two single switches combined) for the separate control of two lamps or groups of lamps.

(b) *All-or-part-and-off* switches for the control of two lamps or groups of lamps.

(c) *Two-way-off* switches for the control mentioned in sub-para. (iv).

(d) *Full-or-dim* lighting, either by using a double filament lamp or by switching two ordinary lamps in parallel or series as desired.

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CHAPTER X.

EXTERIOR ILLUMINATION.

76. *General considerations.*

1. An important branch of illuminating engineering is that dealing with the lighting of streets and other outdoor spaces such as railway yards, disembarkation areas, camping grounds, &c.

From their earliest days electric *arc lamps* challenged the supremacy of gas lamps for exterior lighting, and the advent of *vacuum metal filament lamps* and, later, of *gas-filled metal filament lamps* has greatly extended the use of electric lamps for this form of lighting. Flame arc lamps may still be used for important and very busy thoroughfares where an exceptionally high standard of illumination is required, but the military engineer need not look beyond the gas-filled metal filament lamp.

Exterior illumination is obviously a very different problem from that of house-lighting, where ceilings and walls act as reflectors and send rays of light back towards the floor where they are useful. In the open air there are no such reflecting surfaces and, hence, any light which leaves a lamp above the horizontal is wasted.

The main portion of the problem is, therefore, the utilization of the light that would normally stray above the horizontal. *Reflectors* were originally used, but, owing to the necessary limitation in their size, they were of little value in extending the rays so as to give a more or less even illumination. Most systems of street lighting furnish sufficient illumination near the lamps themselves ; the difficulty usually is in providing enough at the more distant points.

The *avoidance of sharp contrasts* is one of the chief points to be remembered. Persons leaving brightly-lighted premises and stepping into badly-lighted streets are unable to see until their eyes become accustomed to the sudden change. Similarly, if the immediate surroundings of lamp posts are brilliantly illuminated whilst the spaces between them are in comparative darkness, drivers of fast-moving vehicles are unable to accommodate their vision to the rapid changes in illumination. This sharp contrast is responsible for many of the serious accidents that occur.

The *avoidance of glare* is also important. The necessity for hiding completely the source of the light is not, however, of such vital importance as in interior lighting, because the source of light is high enough to be out of the direct line of vision except in the case of distant lamps.

2. In **planning** a system of exterior lighting the following points have to be considered :—

- i. The minimum permissible intensity of illumination.
- ii. The type of equipment most suitable.
- iii. The variation range and the size, spacing, and height of the light units to give the required minimum intensity.

77. *Intensity of illumination.*

1. **Natural illuminants.**—Before detailing what are usually considered reasonable values for illumination of streets, it may be as well to state the values of certain familiar natural illuminants in the same unit, viz., foot-candles.

Such natural illuminants are :—

	Foot-candles.
Night sky—no moon..	0·001
Average moonlight	0·014
Brightest moonlight (clear air) ..	0·1 to 0·16
Daylight (diffused)	2,000 to 8,000

Any attempt to reproduce the conditions of daylight is obviously out of the question. All that can be expected is a reasonably uniform illumination approximately equivalent to that given by average moonlight.

2. **Variation range.**—When considering the minimum illumination required it will be advisable to consider also the variation range, *i.e.*, the ratio of the maximum to the minimum illumination. To take great trouble to obtain the *average* illumination is not only a waste of time but also misleading ; for example, the average illumination of a street brilliantly lighted in some parts and in comparative darkness in others may be high and yet the street may be badly lighted.

In the past a very large variation range was frequently met with, but with a reasonable amount of care in the selection of equipment, spacing, &c., it should not be necessary to exceed 30. For a slightly increased cost, which, in very important thoroughfares, &c., would be well repaid by the better service given, it is possible to reduce this range to 20, or even 15, but beyond this point the increased cost easily outweighs the benefits.

When beacon lighting only (*see* next Sec.) is necessary the question of variation range does not arise.

3. **Desirable intensities.**—Of late years opinions as to the intensity necessary in street lighting have considerably altered, and installations erected are now designed to give

STREET LANTERNS.

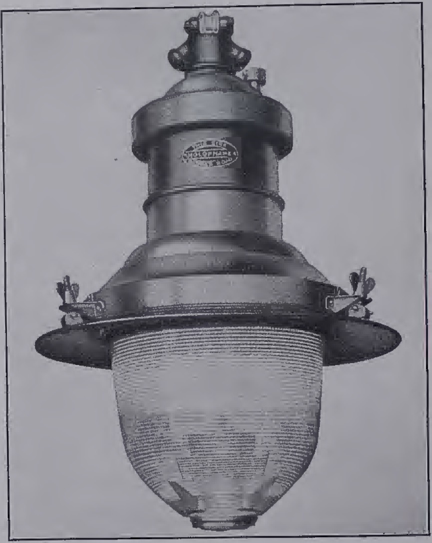


Fig. 1.—Refractor Lantern.

[*By permission of Holophane, Ltd.*

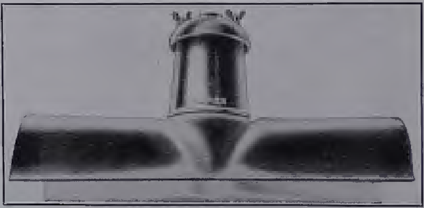


Fig. 2.—" Rodalux " Fitting for 100-w. G.F. Lamp.

(*See Section* 78.) [*By permission of Benjamin Electric, Ltd.*

much higher illumination than those of even two years ago. In 1927 the first British Standard Specification for street lighting (No. 307) was issued. This groups installations into eight classes, each of which is intended to give a certain minimum illumination :—

Class A	2·0 foot-candles or more.
„ B	1·0 foot-candle.
„ C	0·5 „
„ D	0·2 „
„ E	0·1 „
„ F	0·05 „
„ G	0·02 „
„ H	0·01 „

The illumination is measured at a test point depending on the configuration of the system, the point being so chosen that the illumination is the minimum in the street.

78. *Types of equipment.*

1. **Beacon lighting.**—For this class of lighting no directive reflector or refractor is required, but a plain enamelled reflector to prevent the light straying above the horizontal is desirable, and a diffusing bowl should be used if funds are available. Pl. **108**, Fig. 1, shows a typical fitting, which may be used for beacon lighting, though it has good directional properties. The essential points in design are these :—

i. The lamp fittings should be weatherproof.
ii. The fittings should be well ventilated.
iii. The standards should be so designed that the fittings can be easily reached for cleaning and lamp renewals.
iv. The fittings should be placed at least 10 feet above road level, and higher if possible, to reduce glare and render them immune from accidental damage.
v. Means should be provided with directive fittings to ensure that they are oriented correctly with regard to the road, and that the glassware can only be put back in the correct position after cleaning.

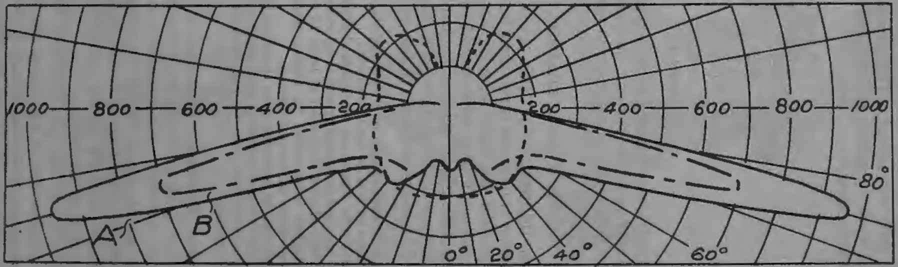
2. **Directive lighting.**—Whenever a certain minimum illumination has to be provided and the question of variation range demands attention, it is necessary to adopt a fitting of a directive character, *i.e.*, a fitting which not only utilizes the light which would otherwise be wasted above the horizontal, but also spreads as much of the available light as possible evenly in the desired direction.

Street lighting fittings are available which will produce almost any distribution of light that can be required. The range of Holophane refractor fittings is comprehensive, and will serve to indicate what can be obtained. The various

PLATE 109.

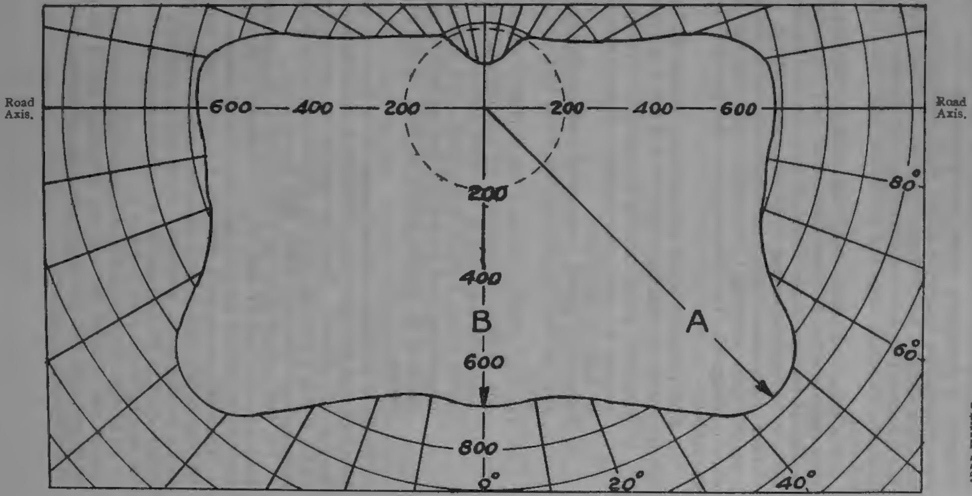
ASYMMETRIC BOWL TYPE REFRACTOR.

Vertical Candle-power Distribution Curve. Curve A 45°, Curve B 90° from the Road Axis.



ASYMMETRIC BOWL TYPE REFRACTOR.

Plan Candle-power Distribution Curve. 15° below Horizontal with 200-watt Lamp.



types of glassware are all interchangeable, and consist of two elements of *clear* glass sealed one within the other. The inner element has horizontal prisms on its outer surface, and the outer element has vertical prisms on its inner surface. The refractors thus have smooth surfaces for cleaning, and the prismatic refraction employed wastes less light than surface reflection.

The horizontal prisms direct the maximum candle-power at an angle of 80° to 70° from the vertical, and this angle can be altered between these limits, to suit the spacing-height ratio, by altering the setting of the lamp in the fitting. The vertical prisms control the plan distribution curve, and consequently differ according to the purpose for which the glassware is designed. The following are the principal types available :—

(*a*) *Bowl refractors*, which almost totally enclose the lamp, and are suitable for spacing-height ratios of 6 to 1 and more.

- i. Symmetric, giving uniform illumination all round and suitable for open space lighting and broad streets lit by lamps in the centre.
- ii. Asymmetric, giving illumination over one hemisphere and suitable for illuminating roads from one side only.
- iii. Two-way (160°), two-way axial (180°), three-way (90° × 180°), and four-way (90°), suitable for narrow roads with standards at the sides, narrow roads with centre lights, T street intersections, and cross-roads respectively, and accordingly having vertical prisms designed to project beams of light at the angles shown.

(*b*) *Band refractors*.—These consist of a band of glassware such that the light coming vertically downwards from the lamp is not affected. They are suitable for spacing-height ratios of 5 to 1 and less, and are procurable to give either a symmetric or a two-way (160°) light distribution.

Pls. **109** and **110** show the polar curves of an asymmetric bowl refractor, and Pl. **108**, Fig. 1, illustrates a Holophane lantern, suitable for use with any bowl type glassware.

The fitting shown in Pl. **108**, Fig. 2, is robust and designed for illuminating long narrow stretches such as railway platforms, landing-piers, or streets. It should be mounted at a height of 14 to 36 feet, and for a variation range of 7·5 to 1 the spacing-height ratio is 4·5 to 1.

In all directive fittings it is of supreme importance that the correct size of bowl, &c., for the particular size of lamp is employed, and that the lamp is placed in the correct position with reference to the bowl.

79. *Height and spacing of units.*

1. **Beacon lighting.**—Experience has shown that the installation of lamps of from 30 to 100 watts at a height of from 10 to 12 feet, and spaced 120 to 150 feet apart will meet the case.

2. **Directive lighting.** — The standards generally employed for this class of lighting vary in height, according to circumstances, between 12 and 35 feet. A mounting height of 35 feet, however, is never required, except for main thoroughfares where very large lamps are employed and a small variation range is necessary. In normal circumstances 13 to 18 feet will suffice. At 13 feet the lanterns will be high enough to be above the range of ordinary vision, whilst above 18 feet cleaning and lamp renewals become difficult. The greater height becomes necessary in large open spaces and in main streets where a moderately low variation range is required.

The lamps can be used either singly or in clusters, though very little is gained by the latter arrangement. The most efficient position for the standards, from the point of view of lighting only, is in the centre of the road. The alternative method of suspending lamp fittings on a wire between the buildings or other points of attachment on either side of the road is preferable from the point of view of traffic. The next best arrangement is for the standards to be *staggered*, *i.e.*, placed alternately on opposite sides of the road. This, however, means increased expense in the laying of mains ; either mains must be laid on both sides of the road or there must be frequent road crossings. Usually sufficiently good illumination will be obtained from lamps on standards along one side of the road only.

3. The British Standard Specification for street lighting recommends that the spacing-height ratio should never be more than 12 (it is usually much less than this). It also lays down the following *minimum* mounting heights :—

Class A	installations		30 feet.
„ B	„		25 „
„ C	„		21 „
„ D	„		18 „
„ E	„		15 „
„ F	„		13 „
„ G	„		13 „
„ H	„	preferably	13 „

The specification also gives a method of estimating the amount of glare likely to arise from an installation.

Very few streets in Great Britain come into Class A; The military engineer will seldom have to consider any but Classes F, G and H. Class F is adequate for fairly busy streets, Class G for other streets with little traffic, and Class H for streets with no through traffic.

Endeavours should be made to light all roads in barrack areas to the standard of Class H. Cases will arise, however, where time, money or the electric power available render this impracticable, and beacon lighting, the main object of which is to guide the traffic by means of lamps acting as beacons, has to be resorted to. It should be remembered that beacon lighting is, as far as motor-drivers are concerned, worse than useless. Occasional lights necessitate continual re-focusing of the drivers' eyes and add considerably to the strain of driving.

The method of calculating spacing and light required can best be explained by an example.

Example.—Suppose that it is desired to provide a minimum intensity of illumination of 0·025 foot-candle with a variation range not greater than 20 for a street 12 yards wide, using gas-filled lamps in bowl refractors at a height of 20 feet. Voltage of supply is 230V.

Spacing of standards.—In order to arrive at the correct spacing for the lamp standards, all that is necessary is to ascertain the point of maximum illumination and the point of minimum illumination so that the given variation range is not exceeded. The point of maximum illumination will obviously be very near the foot of the lamp standard, and, since it may be assumed that no part of the street receives any appreciable illumination from more than two lamps, the point of minimum illumination will be midway between two standards.

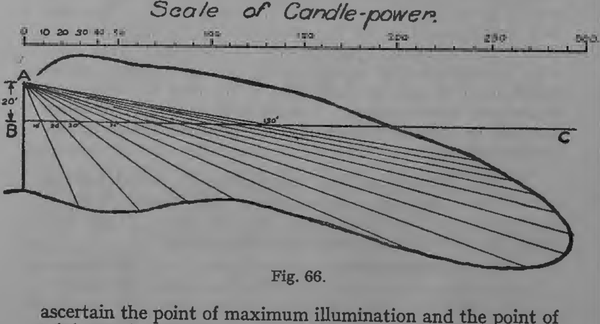


Fig. 66.

Except near the point of maximum illumination, where the additional effect of the distant lamp is negligible, the light received from both lamps must always be taken into consideration as well as the angles of incidence of the light rays (*see* Sec. **59**, para. 1).

On a reproduction of the distribution curve of a 100 m.s.c.p. lamp in a bowl refractor (Fig. 66), draw a vertical line AB from the centre point to represent the height of 20 feet. Draw BC at right angles to AB to represent horizontal distances from the foot of the lamp standard on the same scale.

The illumination intensities at intervals of 10 feet can then be set out in tabular form as follows :—

Distance from foot of standard in feet.	Candle-power in the direction of the distance points in column 1.	Intensity of illumination on the horizontal plane $= \frac{\text{c.p.}}{AB^2 + BC^2} \times \frac{AB}{\sqrt{AB^2 + BC^2}}$
0	56	0·140
10	72	0·129
20	92	0·0814
30	107	0·0457
40	130	0·0291
50	231	0·0296
60	285	0·0225
70	303	0·0156
80	302	0·0108
90	290	0·00740
100	279	0·00526
110	268	0·00385
115	262	0·00330

It will be seen that the maximum intensity of illumination is 0·14 foot-candle. Hence, to keep within the limits of a variation range of 20, the minimum intensity must not be less than 0·007 foot-candle, *i.e.*, 0·0035 foot-candle must be obtained from each of the two lamps.

Examination of the table shows that the required intensity of illumination will be produced at a point between 110 and 115 feet from the lamp. Therefore, allowing for slight losses due to absorption, &c., the standards should be spaced 220 feet apart.

It should be noted that if the lamps are to be staggered, the actual distance between standards on the same side of the street will be $2\sqrt{220^2 - 36^2}$ or 434 feet.

Size of lamp.—The maximum intensity of illumination to be produced by each lamp is $\frac{0{\cdot}025}{2} = 0{\cdot}0125$ foot-candle.

Then, since a 100 m.s.c.p. lamp gives a minimum intensity of 0·00385 foot-candle, the size of lamp required will be

$$\frac{0{\cdot}0125}{0{\cdot}00385} \times 100 = 325 \text{ m.s.c.p.}$$

Reference to B.S.S. No. 161 for lamps shows that the most suitable lamp is the 300W lamp giving 340 m.s.c.p. If this lamp is employed the minimum intensity of illumination will be $2 \times \frac{340}{325} \times 0{\cdot}0125 = 0{\cdot}0261$ foot-candle.

Hence the requirements will be met by the use of 300W gas-filled lamps in bowl refractors at a height of 20 feet, the standards being spaced at 220 feet apart.

80. *Lighting of open spaces.*

1. The lighting of open spaces such as dumps, railway goods yards, and platforms at railheads and bases, the periphery of prison enclosures, and similar places, is frequently called for under active service conditions. Adequate illumination is of great assistance to police and sentries in their duties, especially in preventing theft. Bright lights, if in the middle of a darker area, may attract the undesirable attentions of hostile aircraft, and this danger must be minimized as far as possible by shading the light sources to prevent them throwing any direct light upward.

2. It is impossible to lay down hard-and-fast rules for the lighting of open spaces, but the following recommendations taken from the first report of the Departmental Committee on Factory Lighting (*see* Sec. **62**, para. 2), give a very fair indication of what is necessary :—

i. In all open spaces in which persons are employed during the period between one hour after sunset and one hour before sunrise, in any dangerous parts of the road or way over a yard or other spaces forming the approach to any place of work, the illumination on a horizontal plane at ground level shall not be less than 0·05 foot-candle.

ii. In all parts of factories and workshops (exclusive of "working areas") over which persons employed are liable to pass, the illumination measured on a horizontal plane at floor level shall not be less than 0·1 foot-candle.

iii. In all parts of foundries in which work is carried on, or over which any person is ordinarily liable to pass, the illumination measured on a horizontal plane at floor level shall not be less than 0·4 foot-candle.

The state of the atmosphere, the colouring of neighbouring buildings, and the surface of the area to be lit, all affect both the intensity of the illumination desirable and the utilization factor. In general, ordinary print can be read with 1·0 foot-candle, and men can move about comfortably with 0·5 foot-candle, provided that the illumination is evenly distributed and there are no dark shadows.

Suggested intensities for various outdoor lighting requirements are given in Table **K.**

TABLE K.—RECOMMENDED INTENSITIES FOR OUTDOOR LIGHTING.

	Foot-candles.
Building construction	2 to 4
Building excavation	1 to 2
Fire Brigade and Salvage work	2 to 6
Loading Docks, Wharves	1 to 2
Pageants and Spectacular Displays	2 to 6
Parade grounds	0·2 to 1
Protection of property, Patrol and Prison Work	0·5 to 1·5
Railway goods yards	0·25 to 1
Roadmaking and repairing	1 to 2
Quarries	0·5 to 1·5
Storage yards	0·25 to 1

There are two methods of lighting open spaces :—

(1) *Unit lighting*, in which lamps are mounted on standards as in street lighting, and to which the principles of street lighting apply. It must be remembered, however, that in open space lighting, any particular point receives light from more than two sources, and the effect of all the sources that add appreciably to the illumination must be considered.

(2) *Flood lighting*.—High-power lamps in special projectors are used, mounted on towers 70 or more feet high.

3. **Flood lighting.**—Flood lighting has been used up to date to a much greater extent for lighting vertical surfaces for ornamental purposes than for area lighting. Its merits and demerits as compared with point lighting for this purpose may be summarized as follows :—

(1) Uniform illumination and absence of shadows.
(2) Lower running and maintenance costs.
(3) Higher capital cost.
(4) Elaborate towers necessary to carry the projector.
(5) If the fittings are not carefully adjusted when installed they will cause troublesome direct glare. This glare may be remedied by stippling the cover glasses of the projectors, and by mounting the lights as high as possible.

4. **Design.**—Having decided upon a suitable intensity of illumination the siting of projectors must be settled. This will usually be determined to a certain extent by the layout of the area, and the difficulty of siting towers. The avoidance of shadows is particularly important; when lighting railway yards the projectors should be arranged to project their beams as nearly as possible parallel to the railway lines. If they strike across the lines rolling stock will cause deep shadows.

The type of mirror and the approximate beam spread can then be settled. Projectors can be obtained giving beam spreads of 20 to 70 degrees; for the lighting of horizontal areas where the source of light is comparatively near the surface to be lit, a fairly wide spread is preferable. The beam spread of a floodlight is defined as the angle within which the illumination on a surface, normal to the axis of the beam, does not vary more than 10 to 1.

The candle-power of the lamps to be installed can now be calculated by the ordinary method of Sec. **59**, assuming a coefficient of utilization. This, together with accurate figures for the beam spread, are best obtained from the makers, and the original calculations checked before orders are placed; but for preliminary investigations 0·35 to 0·4 is a safe figure.

A symmetrical design of floodlight when directed at right angles to a surface obviously produces a circular patch of light, but when the beam is directed obliquely, the area lighted will be elliptical. In the latter case, the near edge of the ellipse will be much brighter than the far edge, so the angle of obliquity should not be too small.

The area to be lit will not usually be of the same shape as the beam and a certain amount of light at the edges will therefore be wasted, but when a large area or building is concerned, involving a number of units, the percentage of waste light will be reduced owing to the overlapping of adjacent beams.

When finally adjusting the projectors, the focusing of the lamps and the angle of the beam are of the greatest importance. Apart from the fact that an alteration in the lamp position will alter the beam spread, it will also materially affect the illumination on the working plane.

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CHAPTER XI.

HEATING, COOKING AND COOLING.

81. *General.*

1. Electric heating and cooking will only be discussed briefly, as at the present cost of electrical energy it will seldom be found to be a practicable proposition for W.D. purposes.

2. In Table L an attempt is made to compare the costs of producing a given amount of heat from various sources, but the figures must be used with discretion, as it is impossible to tabulate figures that will apply to all circumstances.

TABLE L.—*Cost of heat units from various sources.*

Fuel.	How used.	Calorific value.	Cost.	Efficiency of conversion.	Cost of 100,000 B.Th.U.
Electricity ..	Central heating boilers.	3,412 B.Th.U. per k.W.h.	½*d.* a k.W.h.	% 90	16·2*d.*
Gas	Fires.	—	9*d.* a therm.	60	15·0*d.*
Electricity ..	Fires, or some other form of room heating, *e.g.*, panels.	3,412 B.Th.U. per k.W.h.	½*d.* a k.W.h.	100	14·6*d.*
Coal	Fires.	12,000 B.Th.U. per lb.	40/– a ton.	20	8·9*d.*
Oil	Central heating.	18,000 B.Th.U. per lb.	90/– a ton.	60	4·45*d.*
Gas Coke ..	Central heating.	11,500 B.Th.U. per lb.	35/– a ton.	50	3·26*d.*

This table, however, does not give a true comparison of the relative running costs for several reasons :—

- i. No money value is placed on considerations of cleanliness, ease of control and operation, &c., in which electrical methods are supreme.
- ii. "Banking" losses are very small with electricity, and thermostatic control is very readily applied and reduces costs considerably.
- iii. Arrangements may be made to take power during off-peak periods, at very low rates, and when this is possible thermal storage may be well worth considering.

82. *Heating.*

1. Heat may be applied to a room or building in two ways :—

(*a*) By radiation. Radiant heat obeys all the laws of light (*see* Chap. VII), and is transmitted, radiated, and absorbed in varying proportions by the substances on which it falls. Air is practically diathermanous, and consequently is not directly heated by radiant heat.

(*b*) By convection. In this case the air nearest the heater is warmed first, and the air currents set up circulate throughout the room.

Practically no useful heat is transmitted by conduction.

The air in a properly ventilated room is changed twice every hour or so, and a well-designed heating system must allow for this as well as for the heat lost through the walls, windows, &c. It is also generally agreed that a large ratio of radiated to convected heat is desirable. Convection heating results in currents of hot air which give the sensation of stuffiness, and cause hot heads and cold feet.

2. Electricity may be used to produce heat in the following ways :—

i. " *Fires.*"
ii. *Low temperature sources* (*a*) *ceiling panels*, (*b*) *plate and tubular heaters.*
iii. *Central boilers, supplying hot water heating systems.*

This method can rarely be justified unless energy can be obtained and stored during off-peak hours at very low rates.

i. Well-designed electric "*fires*" give out 60 to 70 per cent. of their heat in radiation, as compared with the 45 per cent. of a modern gas fire ; but they have many disadvantages. They must be heavily rated if they are to warm up a room in reasonable time, and when controlled by individual switches will probably not be employed to the best purpose. Their main function in a scientifically planned scheme is to act as boosters, the main system being designed to deal with normal conditions, the fires only being put into service during extra cold spells.

ii. (*a*) *Ceiling panels* are probably the most economical and efficient method of electric heating. They consist of resistance wires embedded in plaster and designed for incorporation in ceilings during construction. Panels are made in sections about 2 ft. by 6 ft., and with loadings of 600 watts per section. They are simple to erect, and run at a low temperature—120° F. This last characteristic is very valuable. It eliminates all danger of fire or of elements burning out, and the heat rays from such a source do not throw the "shadows" that are caused by "fires" with elements at 1,500° F. In consequence a very even temperature, not varying by more than 2° F. throughout a room is produced.

For economy and comfort ceiling panels should be run continuously day and night and controlled by thermostats. If switched on each day the air of the building and the building itself will have to be warmed up anew, a lengthy as well as an extravagant process.

ii. (*b*) *Plate heaters* are a form of panel made up for adapting to existing buildings. Panels 2 square feet in area, loaded to 500 to 1,700 watts, are convenient, and may be attached to walls or suspended from ceilings, either by themselves or combined with lighting fittings.

Tubular heaters consist of a resistance wire running down the centre of an iron tube, insulated by china beads or mica strip, and supported on a porcelain bar at close intervals to prevent the wire sagging when heated and coming into contact with the tube. This tube forms the radiating surface, and in one form of construction corrugated fins 2 inches apart are fixed to it to increase its area. A loading of about 60 watts per foot run is adopted.

A favourite place to install tubular heaters is beneath windows, where they act by convection to warm the incoming air, as well as by radiation. By the use of tubular and plate heaters a very even temperature can be produced, but owing to their small area as compared with ceiling panels they have to be designed to operate at a higher temperature, about 200° F. for tubular, and 500° F. for plate, heaters.

iii. *Hot water cylinders* may be heated in two ways:—

(*a*) By a resistance immersed in the boilers and capable of being easily removed. This is the only method applicable where the water is used for washing. A mistake frequently made is to install storage cylinders of too small capacity and of too high loading, designed to be in use for short periods. The only economical method of water heating is to employ fairly large tanks with thermostatic control.

(*b*) By electrodes immersed in water, the current passing through the water and heating it directly. This method is not strictly allowed by the Regulations for the E.E. of Buildings, but a good many electrode boilers have been installed since they were first put on the market in 1926. Care must be taken that the water level remains constant in the heating cylinder, as an alteration of level considerably affects the resistance between the electrodes and the current taken. Control is effected by moving the electrodes.

It possesses the following advantages over coke and oil firing :—

i. No fuel bunkers, chimneys, &c., are necessary, and there is a consequent saving in space occupied.
ii. Operation requires half the personnel of oil-fired systems. On the other hand, the capital and running costs are high. Electric boilers will cost 1½ times as much as oil-fired boilers, and 3 times as much as coke boilers to install.
iii. Table **M** below summarizes some useful data for various systems. If it is desired to calculate the amount of heat necessary from first principles reference should be made to "Notes on Hot Water Supply and Heating Installations for W.D. Purposes, 1929."

TABLE M.—*Particulars of heating systems.*

	Fires.	Low Temp. panel heaters.	Plate heaters.	Tubular heaters.	Convector heaters.
k.W. per 1,000 cu. ft. required to raise temp. 20° F.	2 when warming up. 1 steady conditions.	0·6 to 0·8	0·9 to 1·1.	0·7 with continuous heating and thermostat control. 0·9 day heating only.	0·6 continuous heating. 0·75 day heating only.
Approximate capital cost (1929).	£2 per k.W. plus cost of wiring.	6/– to 8/– per sq. ft. 8/– to 10/– complete with wiring. £12 10*s.* per k.W. installed.	£8 to £8 10*s.* per k.W. and cost of wiring.	£4 per k.W. plus cost of wiring.	
Running temperature.	1,500 to 1,700° F.	120° F. (temp. of ceiling).	500° F.	200° F.	200° F.

83. *Cooking.*

1. Cases frequently occur where the War Department will take electricity in bulk from the grid or a local power station, and being a large user will obtain favourable rates. In comparing electric and other methods on a basis of cost, the energy used should only be debited at the unit charge of the bulk supply, together with any added distribution costs entailed. Cases may arise also where, being a pure resistance load, it improves the system power factor.

Again, the effect of a cooking load on a small W.D. power station, of which there are several, may easily be to improve its load factor and its efficiency very considerably.

2. Cooking may be carried out by means of :—

(*a*) Self-contained utensils, each with its own heating element.

(*b*) A range consisting of an oven, or grill, and one or more hot plates of different sizes.

A higher efficiency can be obtained by using self-contained saucepans, frying-pans, &c., but the obvious disadvantages—high first cost, clumsiness of long flexible connections, and the number of expensive utensils required—prevent this method of cooking being used to any extent. Kettles with self-contained elements often form part of cooking equipment for reasons discussed later.

3. The fundamental consideration in cooker design is safety. At present, and for many years to come, it will be impossible to obtain apparatus without exposed metal parts. All cooker wiring should be carried out in screwed conduit, and all metal solidly earthed, preferably by more than one connection. In addition to the switches on the cooker there should be adjacent a double-pole switch-fuse, not too heavily fused, a pilot lamp, and a three-pin wall socket; these can conveniently be assembled together.

4. *Ovens.* Electricity has the great advantage for warming ovens that heating elements can be placed at the sides, the top or the bottom. The relative merits of these positions is still unsettled, but a mixture of side and bottom heat is usually satisfactory. Elements must be easily removable, and those at the bottom must be protected from spilt liquids. Thermometers are often fitted, but are not entirely reliable, and will be disregarded by most cooks.

5. *Hotplates.* If hotplates are badly designed or unintelligently used, cooking, particularly the boiling of water, will be very slow, and this fact has considerably prejudiced electric cooking. Utensils warped or the wrong size are largely responsible for wasted time and electrical energy, as may be seen from para. 6 of this section, and it is consequently of the utmost importance that personnel put in charge of electric cooking should be intelligent and receive preliminary elementary instruction.

Both open and enclosed hotplates are available. The former are more efficient, as the saucepan is almost directly in contact with the heating element, but are easily damaged by spilt liquids, and modern enclosed types, with a consumption of 1,500 to 2,000 watts, used with proper utensils are recommended.

6. *Consumption and loading.* For economical electric cooking it is essential that special saucepans and frying-pans, with machined bottoms thick enough not to warp, and the same size as the hotplate, should be used. Such utensils, with bottoms $\frac{3}{16}$ inch or $\frac{1}{4}$ inch thick, will cost 50 per cent. more than good ordinary ones, but the lower consumption and greater speed of cooking will soon repay the difference, as the following table shows :—

	Time taken to boil half a gallon of water from 60° F.	Energy used.
	Minutes.	Watt-hours.
Saucepan flat and same size as hotplate	9·5	0·28
Saucepan flat and too small	10·75	0·32
Saucepan flat and too large	13·0	0·39
Saucepan warped	23·0	0·70

The following are the average loadings of various apparatus :—

Kettles	600–850W.
Saucepans, 1 pint ..	400W, 12 pints 1,500W.
Hotplates	1½–2kW.
Ovens	1,000–1,100W per cub. ft. full heat.
Complete cookers ..	4–6·5kW.

7. Recent experience of electric cooking on a large scale in battalion cookhouses at home has brought out the following points :—

- i. The **kWh** required per man per day can be brought down to 0·7 unit for cooking purposes only.
- ii. At present prices (1931), electric cooking should be considered whenever a rate of less than ½*d.* per unit is obtainable.
- iii. Electric cooking permits of great saving of labour in the cookhouse.
- iv. High efficiency is shown by combined steam and electric cookhouses. It is better to avoid boiling water by electricity.

The ordinary battalion staff is capable of operating electric cooking plant.

Opportunities for waste are considerable, however, and the consumption requires frequent check. Meters should be installed for this purpose.

84. *Electric fans for cooling purposes.*

Ceiling fans.—These machines do not ventilate in the true sense of the word, but merely keep air in motion, and they are therefore particularly useful in hot climates where buildings are so constructed that the problem is rather to secure the cooling influence of air in motion than to increase the natural air supply to the room.

Owing to the long hours of continuous running to which fans are subjected the question of *lubrication* is of paramount importance. Whether ball-bearings are used or not, an oil bath appears to be almost essential for satisfactory performance. Good modern fans will run twelve months without attention to the lubrication.

Silent running is also imperative, particularly when the fans are in use all night.

D.C. ceiling fans are invariably fitted with series-wound motors of ordinary design, and A.C. ceiling fans usually have shaded pole, single-phase induction motors, the stator being inside, fixed to the down-rod, and the rotor outside carrying the blades.

The blades are generally of aluminium, three in number.

The energy efficiency of these fans is low, about 25 to 40 per cent., but the real criterion of performance, however, is the "**Service Value,**" which is the output of air in cubic feet per watt of input, measured as described in B.S.S. 367, the British standard specification for Ceiling Fans.

The following table gives typical test figures for good fans of modern design :—

	Dia. of blades.	V.	I.	W.	P.F.	Speed r.p.m.	Max. air speed.	Output in cu. ft. per min.	Service value cu. ft. per watt.
D.C. ..	56"	228	0·4	91	—	190	776	15,900	175
A.C. 50 cycles	60"	228	0·75	93	0·545	180	506	12,300	132

A.C. fans are much less efficient than D.C. and their power factor is very low. For these reasons conversion from A.C. to D.C. has been common practice in the past in India where the fan load is relatively large.

Satisfactory static condensers can now be obtained, however, at a reasonable price, and are being used largely for power factor improvement. An 8 μF condenser, costing about £2, if connected in parallel with the A.C. fan of which particulars are given above, will bring up its P.F. to 0·99 approx. (at 230 volts, 50 cycles).

Speed regulators are usually specified to give three running speeds and an " off " position. When a condenser is fitted it is usual to incorporate it in the speed regulator, and if the condenser is not permanently connected across the motor terminals, arrangements must be provided for discharging the condenser when the regulator is in the " off " position.

Desk fans (B.S.S. 380).—These fans are of portable type, with four 12-inch or 16-inch diameter brass blades. They run at relatively high speeds, 1,000 to 1,500 r.p.m.; and the blades must therefore be well guarded. The motors are usually series wound with laminated fields, and can be used on A.C. of one particular frequency as well as D.C. In places where there is much sand, however, it is sometimes found preferable to use desk fans with *induction motors* (when A.C. is available). The frequency must be specified when ordering A.C. fans.

A 12-inch fan takes about 30 watts, and a 16-inch fan about 55 watts. The power factor of the A.C. fan is low (0·5 to 0·6).

Though mainly used as breeze-producing machines, desk fans can be arranged in a wall opening or near an open window, so as to perform a certain amount of true ventilation.

The D.W. specification for desk and ceiling fans is given in the contract circular setting forth the terms and conditions of the running contract for the supply of these fans.

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106. Electrically Heated Cooking Ranges.

CHAPTER XII.

ESTIMATES FOR ELECTRICAL SERVICES.

85. *General considerations.*

Electrical and Mechanical Services are carried out in a similar manner to other R.E. Services. The Regulations and a considerable amount of other information on the subject are given in "Regulations for R.E. Services," particularly Part II. Rough estimates are prepared on A.F. M.1428, and approximate and detailed estimates on A.F. M.1429.

As the work involved in the preparation of a lighting scheme involves some points of special interest, one method of arrangement will be outlined.

86. *Preliminary estimate for a lighting service.*

1. It will not always be practicable to prepare detailed estimates for a service in the proposal stage, and a first approximation must be arrived at from past experience. The following figures may be assumed for ordinary military accommodation fully occupied :—

Points per head (all ranks) ..	1 to 1·5
Watts ,, ,, ..	30 to 60

The lower figures are about right for ordinary battalion accommodation, and the higher for depot barracks where troops are in semi-permanent camps, and in war time the allowance may be reduced.

2. *Comparative costs.*—Table N is a tentative comparison of the costs of the various systems of wiring in 1930. The cost of fittings must be estimated from catalogues, general figures being of no value.

3. *Time required.*—Here again figures will vary enormously with circumstances, such as travelling time and wiremen's skill. The following figures are only offered as a very rough guide :—

Cleat wiring ..	4 points per day for a wireman and mate.
T.R.S. or metal-sheathed wiring	3 ,, ,, ,, ,, ,, ,,
Screwed conduit wiring ..	2 ,, ,, ,, ,, ,, ,,

4. *First cost of distribution.*—This is more difficult to guess at than the cost of the interior wiring.

It varies between wide limits depending on the size of the

TABLE N.—*Cost of internal wiring per point.*

	CLEAT.			T.R.S.			METAL SHEATHED.			STEEL.			CONDUIT.		
										Screwed enamelled welded heavy gauge.			Screwed galvanized welded heavy gauge.		
	Labour.	Stores.	Total.	Labour.	Stores.	Total.	Labour.	Stores.	Total.	Labour.	Stores.	Total.	Labour.	Stores.	Total.
Wood Building	6/0	10/0	**16/0**	7/6	11/0	**18/6**	7/0	10/6	**17/6**	11/0	12/6	**23/6**	11/0	15/0	**26/0**
Brick Building in course of erection ..	7/6	11/0	**18/6**	8/6	12/6	**21/0**	8/6	11/6	**20/0**	12/6	13/6	**26/0**	12/6	16/0	**28/6**
Old Brick Building ..	9/0	11/0	**20/0**	10/0	12/6	**22/6**	10/0	11/6	**21/6**	14/0	13/6	**27/6**	14/0	16/0	**30/0**

The figures are for plain pendants up to the lampholder, but *excluding lamps and reflectors*. They include for Disboards and D.P. Switch Fuses, *but not for Meters*. It is assumed that in a new building the T.R.S. metal-sheathed or conduit wiring will be concealed throughout, and that in an old building it will be run on the surface wherever possible. No allowances are made for overhead charges or profit. Labour charges are based on wages of 1*s*. 6*d*. per hour. Twenty yards of single wire are assumed per point. For other lengths the relative costs are approximately as follows :—

10 yards per point	0·84
15 ,, ,, ...	0·92
20 ,, ,, ...	1·00
25 ,, ,, ...	1·08

The figures are intentionally rather on the high side, since they are intended for estimating purposes. A small percentage of wall plugs, wall brackets and rise and fall fittings will not appreciably affect the average cost per point for the whole job. Ordinary *dry* situations are assumed. In very damp situations the cost of the fittings will be much greater and the additional earth wire required will add still further to the *cost* of the T.R.S. and Cleat Systems.

area involved and the extent to which overhead lines are practicable. Figures vary from 7*s*. 6*d*. to 25*s*. per point.

A preliminary survey of the area should be made to get a general idea and note difficulties likely to be experienced in the distribution.

Perhaps 15*s*. *per point* is a fairly safe preliminary estimate.

5. *Annual consumption of energy.*—When an electric light installation is proposed, the annual cost of energy must be estimated in addition to the cost of the installation itself. It will be necessary to know the probable hours of use of the lamps, which will depend upon the class of building, the habits of the occupiers, the locality, the latitude, and so forth. In an ordinary private house, a sufficiently close approximation will be arrived at by the assumption that every light in the house will be on for from ¾ to 1½ hours each day throughout the year. For a small house or cottage, this figure will have to be increased to about 2½ hours a day, whereas in barracks the number of hours per annum will vary from 600 to 1,200, according to the degree of occupation.

87. *Detailed estimates.*

1. The service having been approved, the exact method to adopt in getting out the detailed estimate is a matter of experience, and varies with the size of the service. The following notes may be found of assistance to the beginner in preparing an estimate for a service of the order of 500–1,000 points. Facility of check of results should be kept in mind throughout.

2. Fill in Table **O** for each building. Estimate watts required in each building and enter (in pencil) on a small-scale plan.

3. Provisionally group buildings for service connections and mark (in pencil) apparently convenient positions for building brackets, poles, and external lamps. Also show feeding point or points.

4. Fill in Table **P** (Schedule A of D.W. Specification No. 5 for Internal Wiring) as far as possible in accordance with Barrack Synopsis and D.W. Specification No. 12 (Electric Light Fittings).

5. Mark positions of points and switches on plan, giving them identification numbers. The following rules should be observed :—

i. Number all lamps consecutively throughout the building or buildings, taking those of No. 1 sub-circuit first, those of No. 2 sub-circuit next, and so on. In a large scheme it is recommended that sets of numbers, *e.g.* 1 to 99, 100 to 199, &c., irrespective

TABLE O.—*Schedule of electric light, lamps, and fittings.* (A.F. K. 1258)

POSITION.	Area : Square feet.	Scale : Square feet per watt.	Total watts required.	LAMPS AT 230 VOLTS				FITTING.		Wall sockets and plugs.	Switches.	Points.	Particulars of distribution boards, fuzes, switches, meters, &c.
				Type.	Watt.	No.	Total watts.	Type.	No.				
Group V.—Married Officers' Quarters—													
Hall	67			I.F.	15	1	15	A.3	1		1	1	*D.P. Switch Fuse*—15 Amp. *Distributing Fuse Board*—2-way, 15 Amp. *Meter*—2½ Amp.
Dining-room	182	3	61	,,	60	1	60	C.3	1	1	2	2	
Drawing-room	216	3	72	,,	60 15	1 1	}75	C.3	1	1	2	2	
Bedroom No. 1	182	6	30	,,	40	1	40	A.3	1	1	2	2	
Bedroom No. 2	108	6	18	,,	25	1	25	A.3	1		1	1	
Bedroom No. 3	104	6	17	,,	25	1	25	A.3	1		1	1	
Servants' bedroom	96	8	12	,,	15	1	15	A.1	1		1	1	
Kitchen..	140	6	23	,,	25	1	25	A.1	1		1	1	
Scullery..	63	6	10	,,	15	1	15	A.1	1		1	1	
Bathroom	34			,,	15	1	15	A.1	1		1	1	
W.C.	15			,,	15	1	15	A.1	1		1	1	
Boxroom	20			,,	15	1	15	A.1	1		1	1	
Store	15			,,	15	1	15	B.2	1		1	1	
Larder	10			,,	15	1	15	A.1	1		1	1	
Landing	108			,,	15	1	15	A.3	1		2*	1	* 2-way switches
					Total watts		395					18	

TABLE P.—*Schedule A of D.W. standard specification (slightly abridged).*

Sheet No.....of....Sheets.
......Wiring System.

Plan No.	Building and Room.	Meter 2½ A.	Distributing Fuse Board.		Points.	LAMPS.				FITTINGS.						SWITCHES.							SHADES.			Total price for complete wiring of each building to be entered.			Remarks.
			L.10.			15 W.	25 W.	40 W.	60 W.	Pendants.		Bracket.	Bowl.	Wall socket.	Table standard.							D.P. Switch fuse.	Iron 10".	Opal glass.	Table standard card-board.	£	s.	d.	
										A.1.	A.3.	B.2.	C.3.	G.2.	H.1.	L.1.	L.2.	L.3.	L.4.	L.5.	L.8.	L.9							
	Group V.—Officers' Quarters—		Metal cased.	No. of ways.																									
	Hall				1	1					1						1							1					
	Dining-room ..				2				1				1	1		2													
	Drawing-room ..				2	1			1				1	1	1	2									1				
	Bedroom No. 1 ..				2			1			1			1			2		1					1					
	Bedroom No. 2 ..				1		1				1						1		1					1					
	Bedroom No. 3 ..				1		1				1						1							1					
	Servants' bedroom				1	1				1							1						1						
	Kitchen				1		1			1							1						1						
	Scullery				1	1				1										1			1						
	Bathroom ..				1	1				1										1			1						
	W.C.				1	1				1										1			1						
	Boxroom				1	1				1								1					1						
	Store				1	1						1						1					1						
	Larder				1	1				1								1					1						
	Landing	1	1	2	1	1					1										2	1	1	1					
	TOTALS ..	1	1	2	18	10	3	1	2	7	5	1	2	3	1	4	7	3	2	3	2	1	8	5	1				

of the number of lamps initially installed, should be allocated to blocks of buildings or areas.

ii. Distinguish between brackets, pendants, &c., on the plan.

iii. Mark the exact position of the distribution board, or boards.

iv. Distinguish clearly between sub-circuits.

v. Never show upper-floor wiring on a ground-floor plan, and *vice versa*.

vi. Number switches to correspond with the lamps which they control. (Alternative switches should be numbered distinctively, *e.g.*, S.26a and S.26b.)

Distribution boards.—Having gone through all the rooms in a building select position for the D.B. and mark it on the plan, having regard to (1) Accessibility, (2) Desirability of keeping all sub-circuits of approximately the same length, and (3) Keeping down length of run from service connection to D.B. These three requirements are usually conflicting and a compromise must be made.

Group points into " circuits " or " ways " and determine particulars of D.B's. required. In large buildings it will frequently be necessary to have main distribution boards and a number of branch distribution boards.

(*e*) Particulars of D.P. Switch-Fuses and Meters can now be entered on the form and their location shown provisionally. It may be necessary to alter the position in some buildings after the survey of the area in (6) following.

6. Survey area to confirm (or otherwise) the choice of pole sites, &c., provisionally selected in (3).

There may be drains in the way, no room for necessary stays; building brackets may be feasible in some cases instead of poles, cable may be necessary across parade grounds, &c.

7. *On return to the office* complete and ink in Tables **O** and **P** and the small-scale plan showing distribution, services, external lamps, &c.

Mark on each cable and overhead span, including service connections, the number of wires required and the current to be carried at full load. Then enter in *size* of conductors calculated tor a maximum drop of 2 per cent. at full load.

The procedure now depends upon whether the job is to be carried out by *contract* or by *direct labour*.

8. *By Contract.*—Fill in the System of Supply, Type of Wiring, &c., on D.W. Specification No. 5. Arrange the sheets

of Schedule A in order of Service Numbers, Distribution Board Numbers and Final Sub-circuit Numbers.

The contractor will be supplied with a copy of the small-scale plan prepared in para. (7) above, with the position of points and switches indicated thereon as well. The contractor need not adhere rigidly to the distribution routes, if he can give good reasons for departing therefrom.

9. *By direct labour.*—In this case detailed estimates must be prepared (*see* R.E.S. II, para. 1 (1)) with lists of the stores required, and the first step will be to prepare large-scale plans showing the horizontal runs from services to M.D.B's., M.D.B's. to B.D.B's., and from B.D.B's. to points and switches. In laying out the sub-circuits and drawing them, attention should be paid to the following details :—

i. Select routes that are easy to trace and conveniently accessible with the least possible disturbance to walls, floors, and ceilings.
ii. Arrange where possible for important rooms to be on more than one sub-circuit, so that, if one sub-circuit fuse blows, light will still be available.
iii. Do not run through chimneys or chimney breasts.
iv. Avoid diagonal runs, except possibly across open roofs.
v. Keep clear of waterpipes, more particularly hot-water pipes.
vi. Keep as far away from gas-pipes as possible.
vii. Avoid possibility of contact with metal work.
viii. Ensure that switches are easily accessible and never behind doors.
ix. Fix all wall sockets at least 3 feet from the floor. If placed lower, they are liable to injury.
x. In huts, or positions subject to excessive vibration, lampholders should, if possible, be suspended by flexible wire and not fixed direct to brackets or back plates.
xi. In stables, fix all switches, &c., in such positions that it is impossible for horses to come in contact with them.
xii. Even though the expenditure of a certain amount of extra wire is involved, it will frequently be found economical to arrange routes so that the wiring may be secured to woodwork rather than to brickwork or masonry.
xiii. Draw each sub-circuit in a different colour.

The wireman need not adhere rigidly to the runs as shown on these plans, but they assist (in the office) in checking quantities, and (on the job) they ensure that points are connected to the correct final sub-circuits and are controlled from the correct positions.

10. *Sub-circuit diagrams.*—In a large installation it will not be practicable to show the horizontal wiring runs of all sub-circuits on the general plan—nor is it necessary. Reliance can be placed on the wiring foremen and the wiremen, who should be experienced men, for the economical and efficient wiring of the points shown on the plan.

In some cases, however, it is necessary to draw out one or more complete sub-circuit diagrams :—

(i) Where the foremen and wiremen are inexperienced.

(ii) In estimating for the wiring of several similar buildings, great accuracy can be obtained by making a complete diagram for one, and multiplying the quantities taken off it by the number of buildings.

An example of a sub-circuit diagram is given on Pl. **111.** According to the usual convention vertical runs are shown diagonally, but not to scale ; the positive lead, or switch feed, should be shown in red, the negative lead, or lamp feed, in black, and the neutral wire, or switch wire, in black, either dotted or chain dotted.

The following information should be given on all circuit diagrams :—

i. The number of the circuit.
ii. The numbers of the lamps on the circuit.
iii. The scale.
iv. Which lead is to scale (usually the negative).
v. The number of points on the circuit.
vi. The total wattage.
vii. The length of all vertical runs.
viii. The location of runs.

11. *Price lists of stores are now necessary.*—The prices will be found (except for special fittings) in either :—

(*a*) D.W. Contracts.
(*b*) R.A.O.D. Vocabulary of Stores.
(*c*) R.E. Vocabulary of Stores. The prices in this book are for rough costing purposes only, and should not be taken as firm quotations.
(*d*) G.P.O. Rate Book and Vocabulary of Stores. 22½ per cent. has to be added to the prices given to cover storekeeping charges.

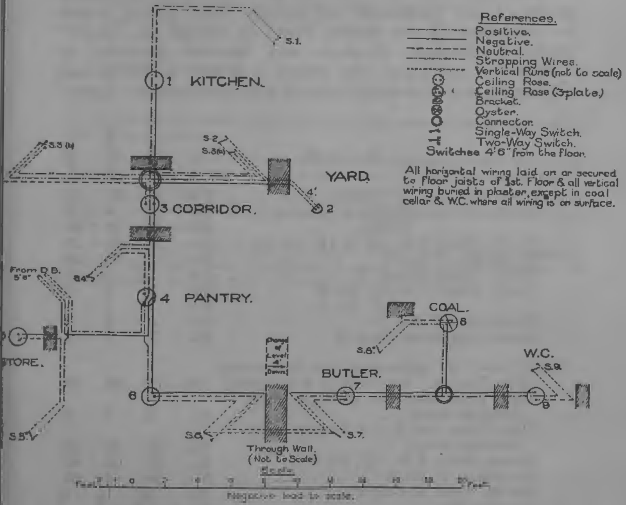
Lists (Section VI of A.F. M 1429) should first be prepared under four heads :—

(i) *Electric Fittings*, including Switches and Distribution Boards. Details are given in D.W. Specification No. 12, but the stores required for their installation must also be allowed

PLATE 111.

SUB-CIRCUIT DIAGRAM. No. 1.

Lamps 1 to 9. Total Watts 240. No. of Points 9.



for, including the runs from the Main D.P. Switch Fuse to the M.D.B., and from the latter to the B.D.B's.

(ii) *Meters*, including stores for fixing.

(iii) *Wiring stores*. The number of points will be extracted from Table **P**, and the detail of stores per point from Table **Q**.

In a small job the length of wire per point should be measured up from the plan, but in a large job involving (say) 500–1,000 points it will seldom be practicable to do this. But with a little experience a close approximation to the length of wire required can be obtained by estimating the lengths as " Short " (15 yards), " Medium " (20 yards) or " Long " (25 yards).

A number of points close together which sometimes occur in offices and workshops, particularly when several points are controlled by one switch, would be classed as " Short," Ordinary Soldiers' Quarters and Married Quarters as " Medium," and Large Unit points in Messes, Institutes and Gymnasia, as well as small lamps in long corridors, as " Long."

TABLE **Q.**

		Short.	Medium.	Long.
Cleat Point " A."				
•Cable, Electric, " J " 0·002	Yds.	15	20	25
Cleats, Porcelain, Treble, ½" grooves	No.	3	4	5
,, ,, Double, ,,	No.	9	12	16
Screws, Brass, R.H., 1⅛" or 1¾", No. 10	No.	15	20	26
*Rawlplugs, 1", No. 10	No.	15	20	26
Blocks, Wood, Round, 3"	No.	1⅓	1⅓	1⅓
Screws, Brass, F.H., 2", No. 10	No.	8	3	3
,, ,, ,, ¾", No. 6	No.	1	1	1
*Rawlplugs, 1⅛", No. 10	No.	3	3	3
Bushes, Insulating, Plain, ¾"	No.	2	2	2
T.R.S. Point " B " (wires fixed with fibre cleats).				
Cable, Electric, " M " 0·002 (T.R.S., Single)	Yds.	15	20	25
Clips, Fibre, Size B.3 (3 single wires—two-hole fixing)	No.	3	4	5
Clips, Fibre, Size 7, C.2 (2 single wires—two-hole fixing)	No.	22	28	35
Screws, Brass, R.H., 1¼", No. 6	No.	50	64	80
*Rawlplugs, 1", No. 6	No.	50	64	80
Blocks, Wood, Round, 3"	No.	1½	1½	1½
Junction Box	No.	½	½	½
Screws, Brass, F.H., 2", No. 10	No.	3	3	3
,, ,, ,, ¾", No. 6	No.	1	1	1
Bushes, Insulating, Plain, ¾"	No.	2	2	2
*Rawlplugs, 1⅛", No. 10	No.	3	3	3

Note.—A small number of larger fibre cleats should be allowed for the whole scheme.

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* *Plugs.*—One plug has been allowed per screw. This high proportion will be required only in cases where the whole of the wiring is fixed to brick walls.

TABLE Q—*continued.*

		Short.	Medium.	Long.
Conduit Point " C."				
Tubing, ¾", Galvanized	F.R.	15	20	25
Cable, Electric, " J " 0·002	Yds.	15	20	25
Bends, Inspection, ¾"	No.	1	1	1
Saddles, Single, ¾"	No.	5	7	8
Pipe Hooks, ¾"	No.	2	2	2
Screws, Brass, R.H., 1", No. 6	No.	10	14	16
*Rawlplugs, 1", No. 6	No.	10	14	16
†Boxes, Circular, Ordinary, ¾" (Terminal, Tee, Elbow, or Through S.B. or B.O. as required)	No.	1½	1½	1½
Covers, Box, Circular, Ordinary Fibre ..	No.	1	1	1
Screws, Fibre Cover, No. 2 B.A.	No.	2	2	2
Covers, Box, Circular, Ordinary Iron ..	No.	½	½	½
Screws, Iron Cover, No. 2 B.A.	No.	1	1	1
Couplers, Screwed, ¾"	No.	½	½	½
Tee's Inspection, ¾"	No.	1	1	1
Interior Porcelain	No.	½	½	½

A few extra conduit boxes of various patterns should be ordered for the whole scheme.

Note.—This table includes all the stores necessary per point *except* the conduit and fittings for the switch runs, for which *see* Table **S**.

* *Plugs.*—One plug has been allowed per screw. This high proportion will be required only in cases where the whole of the wiring is fixed to brick walls.

† The proportion of each type required will depend on the particular job in hand, but it should be borne in mind that a " Tee " box can, in emergencies, be used as a " Through " or an " Elbow."

Tabulate results as in Table **R**.

TABLE **R**.—*Statement of stores required.*

ARTICLE.	POINT.						TOTAL.	AMOUNT TO BE ORDERED.	OBTAINABLE FROM.	RATE.	COST £ s. d.		
	Short.		Medium.		Long.								
	No. per point.	No. of points.	No. per point.	No. of points.	No. per point.	No. of points.							
Screws, Brass, R.H., 1", No. 6	10	—	14	15	16	2	242	2 gross	R.A.O.D. (G.1)				
Cable, Electric, "J." 002" Yds.	15	—	20	,,	25	,,	350	350	R.A.O.D. (W.2)				
Interiors, Porcelain	½	—	½	,,	½	,,	8½	9	D.W.C.C.				
Tubing, Galvanized, ¾" Ft.	15	—	20	,,	25	,,	350	350	D.W.C.C.				
Bends, Inspection, ¾" ..	1	—	1	,,	1	,,	17	18	,,				
Saddles, Single, ¾"	5	—	7	,,	8	,,	121	1 gross	,,				
Pipehooks, ¾" ..	2	—	2	,,	2	,,	34	3 doz.	,,				
Boxes, Circular, Ordinary, ¾"	1½	—	1½	,,	1½	,,	25½	6	,,				
Boxes, Through, ¾"								6	,,				
Boxes, Elbow, B.O., ¾" ..								18	,,				
Covers, Box, Circular, Ordinary Fibre	1	—	1	,,	1	,,	17	18	,,				
Screws, Fibre Cover, No. 2 B.A.	2	—	2	,,	2	,,	34	3 doz.	,,				
Covers, Box, Iron	½	—	½	,,	½	,,	8½	12	,,				
Screws, Iron, Cover, No. 2 B.A.	1	—	1	,,	1	,,	17	2 doz.	,,				
Couplers, Screwed, ¾" ..	½	—	½	,,	½	,,	8½	9	,,				
Tees, Inspection, ¾"	1	—	1	,,	1	,,	17	18	,,				
Rawlplugs, 1", No. 6	10	—	14	,,	16	,,	242	2 gross	,,				
							TOTAL COST OF STORES			£			

A similar table should be prepared for the Switch runs, for which Table **S** will be found useful.

TABLE **S**.

Switches on Wood Blocks.

Blocks, Wood, Round, 3"	No.	1
Screws, Brass, F.H., 2", No. 10 ..	No.	2
,, ,, F.H., ¾", No. 6 ..	No.	2
,, ,, R.H., 1", No. 6 ..	No.	6

TABLE S—*continued.*

Rawlplugs, 1½", No. 10	No.	2
,, ,, 1", No. 6	No.	6
Tubing (Conduit), Light Gauge, Brazed Joint, ¾", Galvanized	F.R.	6
Saddles, ¾"	No.	3
Bushes, Insulating, Exterior, ¾" Plain	No.	2
Switches on Conduit Boxes.		
Boxes, Circular, Ordinary (S.B. Terminal or Through as required)	No.	1
Covers, Box, Circular, Ordinary Fibre	No.	1
Screws, Fibre Cover, No. 2 B.A.	No.	2
Screws, Brass, F.H., ⅝", No. 6	No.	2
Tubing ¾", Galvanized	F.R.	6
Saddles, ¾"	No.	2
Screws, Brass, R.H., 1", No. 6	No.	4
Rawlplugs, 1", No. 6	No.	4
Tee Inspection, ¾"	No.	½

(iv) *Distribution services and external lamps.*—All poles, services and external lamps should be numbered, and list of stores for the exterior wiring prepared on the lines indicated above. The stores for the services should include the cable up to the D.P. main switch.

Tables **T** and **U** may be found useful when estimating for H.V. and L.V. Overhead Line Stores.

It will be clear that it is impossible to compile such tables to suit all circumstances, but the figures should be helpful if used with discretion.

The H.V. stores given in Table **T** are for one mile of simple line. Separate lists should be prepared for points in the line requiring special construction such as at road, railway and telephone crossings.

12. We now have lists of the stores required under the headings (i) to (iv). Summaries must be abstracted and lists prepared for indents under the following heads :—

(i) R.A.O.D.

(ii) D.W. Contracts (*a*), (*b*), (*c*), (*d*), &c.

(iii) G.P.O. Demands, which should be sent to the local P.O. Engineer.

(iv) Special sources of supply.

When preparing indents it is advisable to add a small percentage, not usually exceeding 10 per cent., to the estimated quantities.

The material is now available for the completion of A.F. M. 1429, its enclosures and annexures, and for work to be begun directly it is authorized.

TABLE T.—*Stores required for 1 mile of 3-phase high voltage line.* (*150-feet spans.*) *Volts.*

Poles, 30′ long, 8½″ to 9″ butt diameter	No.	40
Insulators, Supporting, Volts, 400 lbs.	No.	150
Insulator Pins for ditto, 400 lbs.	No.	135
Insulator, Pole Brackets for ditto	No.	135
Coach Screws, 3½″ × ½″ for ditto	No.	420
Insulators Tensioning, Volts, 800 lbs. Complete with straining clamp for fixing to pole	No.	4
Ditto Cross Arm	No.	8
Steel Channel Arms, 4″ × 2″ × 4′ long for ditto	No.	4
Bolts, G.I., 8″ × ⅝″ for ditto	No.	4
Wire, Copper, Hard Drawn, 0·162″ diameter (8 S.W.G.) yards 5,400	Lb.	1,300
Wire Copper, Annealed, 14 S.W.G.	Lb.	22
Wire, Stay, G.I., 7 strands/0·16″ diameter, yards 80	Lb.	200
Staples, G.I., No. 4 S.W.G.	Lb.	5
Rods, Stay, G.I., 8′ long, ¾″ diameter	No.	8
Blocks, Stay (Creosoted Timber, 8″ × 4″ × 4′ long)	No.	8
Danger Notices	No.	40
Number Plates	No.	40
Barbed Wire, 14 S.W.G., feet 720	Lb.	40

The following items are necessary for peace conditions, but not absolutely necessary on active service ;—

Roofs, Pole, G.I. Uncut	No.	40
Nails, Rosehead for ditto, No. 160	Lb.	5
Wire, Copper, Tinned, 7/0·064, feet 500	Lb.	45
Wire, G.I., 7/0·064 (45 ton quality), yards 1,800	Lb.	420
,, ,, Annealed, 18 S.W.G.	Lb.	5
Earth Wire, Suspension Fittings	No.	40
,, ,, Tensioning Fittings	No.	4
Staples, Brass, 8 S.W.G.	Lb.	5
Wood, Casing, Creosoted, 2″ × 1″ (grooved for 7/0·064 wire)	Ft. run	50
Nails, Wire, 2″	Lb.	2
Earth Plates, Galv. C.I. 2′ × 2′ × ⅛″	No.	5
Earthing Bows	No.	30
Bird Guards	No.	50

TABLE U.—*Stores required for overhead distribution in hutted camp for infantry battalion* (vide *Pl.* 1, *Military Engineering* (*Vol. VII*), *Accommodation*, 1927).

400/230-*volt 3-phase feeding point near Sergeants' Mess.*

Poles, Wood, 28′ long, 7″ to 7½″ butt diameter	No.	20
,, ,, ,, 8½″ to 9″ ,, ,,	No.	5
Roofs, Uncut	No.	25
Nails, Rosehead	Lb.	3
Insulators, Supporting	No.	160
Insulator Bolts, Swan-neck, screw in pattern, for ditto (Alternatively Straight Pins, Strap Iron Brackets and Coach Screws).	No.	150
Rings, Insulator, for ditto, I.R. or felt	No.	160
Insulators, Shackle, 3″ diameter	No.	85
Links and Bolts for direct attachment of shackle insulator to pole	No.	80

TABLE U—*continued.*

Wire, Copper, Hard Drawn, 0·178" diameter bare, yards 2,000	Lb.	600
,, ,, ,, ,, 0·136" diameter bare, yards 1,300	Lb.	240
,, ,, ,, ,, 0·136" diameter weatherproof insulated	Yds.	700
,, ,, Annealed, 14 S.W.G., bare	Lb.	27
,, ,, ,, ,, weatherproof insulated	Yd.	120
,, ,, ,, bare, tinned 7/0·064, yards 35	Lb.	10
Rods, Stay, G.I., 8′ long, ¾" diameter	No.	8
,, ,, ,, 6′ ,, ⅝" ,, ...	No.	10
Blocks, Stay (Sound timber, 8"×4"×4′ long)	No.	8
,, ,, ,, ,, 8"×4"×2′ 6" long) ..	No.	10
Wire, Stay, G.I., 7/0·16, yards 75	Lb.	112
,, ,, ,, 4/·016, yards 100	Lb.	84
Staples, G.I., No. 4, S.W.G.	Lb.	10
Insulators, Stay	No.	20
Fir Scantling, 3"×3"	Ft. run	350
Bolts and Nuts, Cuphead, square nuts, 10"×⅝" ..	No.	132
Wire, Electric, T.R.S., 0·002 sq. in., single	Yds.	350
Cleats, Porcelain, 2-Way, for ditto	No.	400
Screws, Iron, R.H., 1¾", No. 10, for ditto	Gross	3
Leading-in Tubes, Ebonite, for ditto	No.	132
Chatterton's Compound	Lb.	4

(Poles, Stay Blocks, and Fir Scantling should be creosote impregnated, if possible).

88. *Records.*

(i) *Interior wiring.*—A family tree of the wiring from the Service to the sub-disboards giving sizes of cables, length of runs, &c., should be made out in diagrammatic form and carefully kept up to date. It can then be seen at a glance where the cables are nearing their full capacity and increases checked accordingly. The voltage drop at any point can also be easily calculated.

The diagram should show :—

Sub-Disboard	i. Number of points on each final sub-circuit. ii. Number of Amps. on each sub-circuit.
Connections from Main Disboard to each Sub-Disboard.	Distance, Size of Cables and Safe Current-carrying Capacity. Installed load in Amps. Voltage drop at full load.
Main Disboard ..	Number of Amps. on each Sub-Disboard.
Service Switch to Main Disboard.	Distance, Size of Cables and Safe Current-carrying Capacity. Installed load in Amps. Voltage drop at full load.

(ii) *Distribution.*—A route plan showing buried and overhead supply cables should also be kept in the record file, with full particulars as to lengths and sizes of conductors, voltage drops, &c.

The route plan should include service connections and main interior wiring runs up to Sub-Disboards.

Full particulars of transformers should also be recorded.

(iii) *History sheet* showing :—

(*a*) Authority for installation (copy of authority).
(*b*) Date of erection of installation.
(*c*) How installed, by Contract or by Direct Labour.*
(*d*) Average cost per point for Stores.*
(*e*) Average cost per point for Labour.
(*f*) Date light taken into use (copy of letter to O. i/c Bks.).
(*g*) Source of Supply.
(*h*) Nature of Supply.
(*i*) Charge per unit (copy of letter or agreement with Supply Co.).
(*k*) Method of wiring, conduit, cleat, or T.R.S. (concealed or surface).

(iv) Attached to History sheet :—

List of buildings lit showing number of points and watts per room.
Copy of electrical inventories.
Detailed test of system on erection.
Form for recording subsequent detailed tests of system.
Alterations carried out giving all necessary particulars as essential on history sheet.

BIBLIOGRAPHY.

The Practice of Electric Wiring. D. S. Munro. Elec. Review. 5/-.
Electrical Estimating. J. G. Connan. Spon. 12/6.
I.E.E. Regulations for the Electrical Equipment of Buildings.
Home Office Electricity Regulations.
Regulations for R.E. Services (particularly Part II).
Barrack Schedule (Sec. 11) deals with Electrician's work (mainly renewals and extensions).

D.W. Standard Specifications for E. & M. Services :—
No. 5. Internal Wiring.
No. 12. Electric Light Fittings.

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* When possible the cost of Distribution should be recorded separately.

CHAPTER XIII.

ELECTRIC MOTORS AND THEIR CONTROL.

89. *D.C. motors.*

1. Theoretical considerations.—It will be assumed that the reader is acquainted with the fact that the D.C. motor is in theory the converse of the D.C. generator ; therefore, the field windings may be series, shunt, or compound in the former as in the latter.

i. *Fundamental equations.*

Let T = total torque, including loss torque,
Φ = total effective field flux,
I_A = armature current,
I_F = shunt field current,
N = speed,
V = applied voltage,
E_B = Back E.M.F.,
R_A = resistance of armature plus interpoles plus series coil,
R_F = resistance of shunt coil,
P = output in B.H.P.,
W = input in watts.

Then :—

$$T \propto \Phi I_A \tag{1}$$

$$E_B \propto \Phi N \tag{2}$$

$$E_B = V - I_A R_A \tag{3}$$

$$P \propto TN \tag{4}$$

$$W = V(I_A + I_F) \tag{5}$$

ii. *Torque* (neglecting armature reaction).—In a series motor $\Phi \propto I_A$ and is independent of the supply voltage.

$\therefore T_A \propto \Phi I_A \propto I_A^2$.

In a shunt motor Φ is constant if supply voltage is constant,

$\therefore T_A \propto \Phi I_A \propto VI_A \propto I_A$.

iii. *Starting current.*—From equation (3), $I_A = \dfrac{V - E_B}{R_A}$.

Since E_B is zero when the armature is at rest and $V - E_B$ does not exceed from 3 to 5 per cent. of V under normal running conditions, if a D.C. motor were switched directly on to the mains in the same way as an ordinary incandescent lamp, from 20 to 30 times normal full-load current might be expected to flow before the armature moves. The effects of such an excessive current would be :—

(*a*) Excessive heating of armature and connections.

(*b*) Excessive mechanical stresses in motor and machinery connected thereto, due to too rapid acceleration.

(*c*) Excessive voltage drop in the supply mains, causing inconvenience to other consumers in the vicinity.

(*d*) Excessive power demand on the supply station.

For these reasons, it is necessary to start D.C. motors from rest by connecting them to the mains through a resistance sufficiently high to reduce the starting current to a safe value. This is the principal function of a motor startor.

iv. *Maximum or " Pull-out " torque.*—If it were not for the effects of armature reaction and magnetic saturation in keeping down the value of the flux with large values of I_A, a D.C. motor would be capable of exerting from 20 to 30 times normal full-load torque. This is of theoretical interest only, since a machine would accomplish its own destruction if it were allowed to exert such a torque. In practice the *pull-out* torque of a D.C. shunt motor is usually over six times and that of series and compound motors over ten times full-load torque.

v. *Starting torque of series and shunt motors compared.*—Consider two motors, equal in all respects except the field winding, and requiring the same armature current at full load, and assume that the maximum safe starting current is equal to twice normal full-load current.

If the supply voltage is constant, T is proportional to I_A^2 in the series and to I_A in the shunt machine. Therefore, the series will exert four times and the shunt twice full-load torque at starting, *i.e.*, the series machine is capable of exerting twice as much torque as the shunt. But, mainly from considerations of economy in material, high flux densities are usually employed, and the flux does not continue to be proportional to the current if it much exceeds normal full-load value. Moreover, armature reaction causes a reduction in the field flux. For these reasons, it will be found that, on constant voltage circuits, the series motor has no very marked advantages over the shunt as regards starting torque.

Where, however, there is considerable voltage drop in the mains the result is very different. To take an extreme case, suppose the supply voltage drops to 50 per cent. of the normal. This will not limit the torque of the series motor, since a voltage of about 10 per cent. of normal only is necessary to cause twice full-load current to flow. But in the shunt machine the field is reduced to half its normal value, and, therefore, the maximum value of the starting torque with twice full-load armature current is $2 \times \frac{1}{2} =$ normal full-load torque only.

vi. *Torque and speed. Inherent speed regulation on constant voltage supply.*

$$N \propto \frac{E_B}{\Phi} \propto \frac{V - I_A R_A}{\Phi}$$

$$T \propto \Phi I_A.$$

In a **shunt** motor (neglecting armature reaction) Φ is constant, $T \propto I_A$, and $N \propto E_B \propto V - I_A R_A$.

An *increase of* T therefore means an increase of I_A, a decrease of E_B, and consequently a *decrease of* N.

But $I_A R_A$, which is negligible at no-load, does not exceed 5 per cent. of V at full-load torque, and the *maximum speed variation* between no-load and full-load torque *will not exceed* 5 *per cent.* so long as Φ is constant.

Actually, armature reaction weakens the field, and as this tends to increase the speed, the nett result is a smaller variation in speed than would be conjectured from a consideration of the $I_A R_A$ drop alone. This is only true, however, for gradual changes of load. The compensating effect is negligible when the variations of load are large, sudden, and of short duration.

It is to be noted that, when first starting up a shunt motor, the speed will be about 5 per cent. lower than normal, but will gradually increase as the field coil warms up.

In a **series** motor, $I_A R_A$ is again about 5 per cent. of V at full-load torque. But $\Phi \propto I_A \propto \sqrt{T}$, therefore the speed is inversely proportional to the square root of the torque and consequently falls rapidly as the torque increases. If the load is entirely removed the speed will become excessively great, and, therefore, this type of machine should not be used in cases where such a contingency is possible and there is no attendant.

Pl. **112** shows the type of speed-torque characteristics obtained with series and shunt motors.

vii. *Power demand with varying torque at constant voltage.* Neglecting losses, $W \propto P \propto TN$

and $N \propto \frac{E_B}{\Phi} \propto \frac{V - I_A R_A}{\Phi} \propto \frac{V}{\Phi} \propto \frac{1}{\Phi}$ (neglecting $I_A R_A$, which is small compared with V),

$\therefore$ input $\propto \frac{T}{\Phi}$ approximately.

In a **shunt** motor, Φ is constant, $\therefore W \propto T$.

In a **series** motor, $\Phi \propto \frac{1}{\sqrt{T}}$, $\therefore W \propto \sqrt{T}$.

Now if T is doubled the input to the shunt motor will be doubled also, since the speed change is small, but the input to the series motor will only be increased from W to $\sqrt{2}.W$ because its speed falls from N to $\frac{N}{\sqrt{2}}$. That is, to develop 100 per cent. excess torque, the shunt motor will demand practically twice the power from the supply station and will continue to run at a slightly lower speed, whereas the series machine will do the work with a drop in speed of 30 per cent., and will demand 40 per cent. extra power only (*see* Pl. **112**).

This is the principle reason for adoption of series machines for tramcars and cranes, where the load is very fluctuating and constant speed is not of importance. It is an important point in the interests of the supply station that a heavily loaded tramcar travels slowly uphill.

2. Control of D.C. motors.—Under this heading fall the duties of isolating the machine when not in use, starting and stopping, protecting it from overload, regulating the speed, and reversing the direction of rotation. The control apparatus may be actuated by hand, by variations in pressure or temperature, or by alteration in the level of water or other liquid; further, the control gear can be made automatically to cause the motor to repeat a definite sequence of operations. Numerous types of automatic gear are in commercial use. but simple hand control with no-volt release is usually sufficient for military purposes.

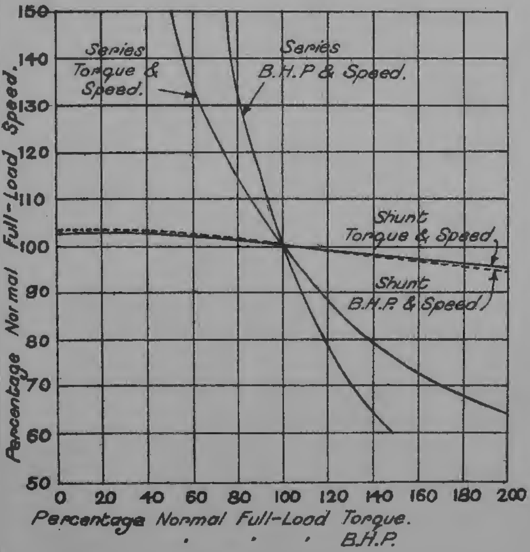
The addition of an ammeter to any type of startor gives

To face p. 378.

Plate 112.

CURVES OF SERIES AND SHUNT MOTORS. (See Section 89.)

TORQUE - SPEED & B.H.P. - SPEED.



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valuable information regarding the extent to which the motor is loaded, and, by indicating when the current taken exceeds the normal amount, draws attention to irregularities. For example, the current required to drive a circular saw is much greater when the teeth are blunt than when the saw is newly sharpened.

3. **Starting.**—A motor startor in its simplest form consists of a rheostat, which performs the double function of a switch and a series resistance which can be gradually diminished as the motor gains speed.

In the case of shunt motors, it is essential that the field magnets should be excited before current is supplied to the armature, and care should be taken that the field receives the full-supply voltage. It is, moreover, most important that the shunt circuit should never be broken, owing to its high self-induction. These two requirements are met by connecting one end of the shunt coil permanently to one of the brushes and the other end to the first contact on the starting rheostat, as shown in Fig. 67 (*b*).

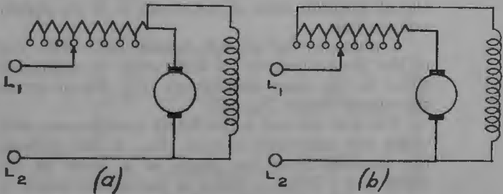

Fig. 67.

The connection shown in Fig. 67 (*a*) is incorrect, because the field gets a reduced voltage at starting, and Φ may be so small that the torque would be insufficient to overcome the friction of the motor and machinery connected thereto. On the other hand, if the machine is started up light it will race (*see* end of this para.). The fact that the starting resistance is always in the field circuit does not cause any inconvenience, since the total starting resistance is small compared with the resistance of the shunt coil.

The resistance of field regulators, when these are used, should be *all out* at starting, *i.e.*, the machine should start with the maximum field strength.

Period to allow for starting.—The proper accelerating period to allow depends upon whether the machine starts up light or on load, the nature of the load (*e.g.*, whether there are heavy parts to set in motion), and the size of the machine.

When full-load torque is required at starting, the time allowed is generally 5 seconds plus ½ a second for each H.P. of the motor rating. Thus a 5 H.P. motor requires 7½ seconds and a 20 H.P. motor 15 seconds.

This rule enables a large machine to be started with a smaller ratio of starting current to working current.

The period can be shortened somewhat when the machine starts up light, but it should be remembered that the field takes an appreciable time to excite, and, if the full supply voltage is applied to the armature before the field is fully excited, a dangerous speed may be attained. The field of a 5 H.P. motor will reach 95 per cent. of its maximum value in 2 to 3 seconds, but the field of a 20 H.P. machine may take 10 to 15 seconds to attain that value.

4. Protection.

i. *Protection against failure of supply.*—B.S.S. 246 and I.E.E. Regulation 119 make it necessary to incorporate in the startor a no-volt release to ensure that the startor handle automatically returns to the *off* position with all resistance in if the supply voltage fails.

Connections of no-volt release coil.—The coil of the electro-magnet (N.V.R.) may be connected either in the shunt-field circuit (Fig. 68) or across the supply mains (Fig. 69).

The first method is the better arrangement with shunt and compound motors, since it also protects the machine from the effects of a break in the shunt coil. When a shunt or compound motor is running light it may attain a dangerous speed, if the shunt-coil circuit is inadvertently broken, by running on the weak field provided by the residual magnetism of the field magnets.

The second method must be used with series motors, and has sometimes to be adopted with shunt motors if they are designed for a large range of speed regulation by field adjustment.

An important facility in connection with no-volt release coils is the possibility of stopping a motor from more than one position. This may be done by simply running two wires to push-button switches, which are placed in convenient positions and stop the motor by short-circuiting the no-volt coil. These wires must naturally be of low resistance compared with that of the no-volt coil.

Great care must be taken to see that the no-volt release mechanism is maintained in working order.

The machine should always be shut down (except in cases of emergency) by opening the main switch, when the operation of the no-volt release can be verified.

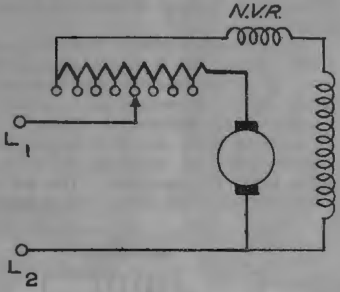

Fig. 68.

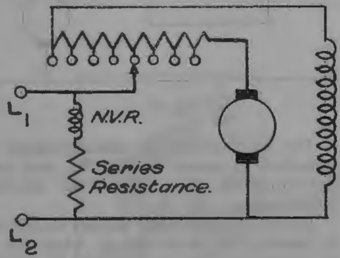

Fig. 69.

ii. *Overload protection.*—The Home Office regulation lays down that fuses or overload circuit-breakers must be installed in *both* supply mains.

For comparatively small currents, fuses are preferable to mechanical devices owing to lower first cost, and the cost of their renewal is not great. For larger currents, however, the difference in first cost is much less and the cost of renewing fuses is greater, and as a mechanical device can be reset instantaneously and without any expense, its use is generally preferable to that of fuses.

A valuable property of a fuse is its *time lag*, which allows momentary overloads to clear themselves when they are not of sufficient duration to cause excessive heating. To obtain a similar time lag with mechanical overload devices, it is necessary to include a dashpot or other equivalent arrangement.

An overload release is frequently added to a motor startor, but it is not essential if separate fuses or circuit-breakers are provided in each supply main. However, an overload release is a fairly cheap addition to a startor, and it is advisable to make use of it in conjunction with a double-pole fuse, adjusting the overload release to trip before the fuses blow. This will often effect a considerable saving in the cost of fuse renewals.

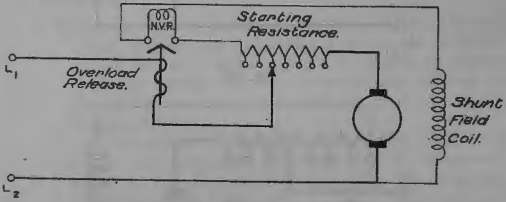

Fig. 70.

The overload release electromagnet is usually connected as shown in Fig. 70, and operates by short-circuiting the coil of the no-volt release electromagnet.

It is to be noted that motors should be stopped by opening the main switch, when the handle of the startor should automatically be released.

5. **Types of startor.**—Pl. **113,** Fig. 1, shows a simple type of face-plate startor with no-volt release only, and Pl. **113,** Fig. 2, illustrates one which is fitted with both no-volt and overload releases. The former has button contacts and the latter renewable contacts.

Pl. **113**, Fig. 3, is a diagram of connections. The startor has three terminals, marked *Line*, *Armature*, and *Field*. One of the supply mains leads direct to the motor. A common mistake is to connect the armature to the line terminal and one of the lines to the armature terminal.

With most startors the lever has to be right on or right off, as the resistance coils are not intended to carry the full current for more than a few seconds.

PLATE 113.

D.C. MOTOR STARTORS.

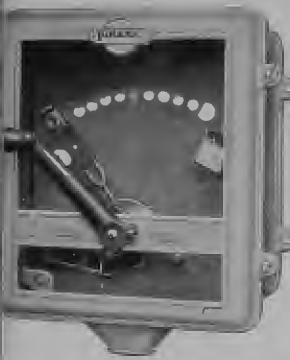

Fig. 1.—With Button Contacts.

Fig. 2.—With Renewable Contacts.

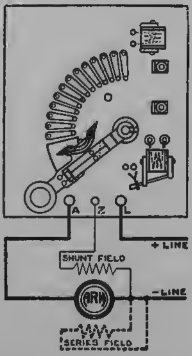

Fig. 3.—Connection Diagram for Starting Rheostat when Compound Wound Motor is used, connect series field as shown dotted.

[*Permission of the Igranic Electric Co., Ltd.*

If the starting resistance is also required as a speed-regulating series resistance, the wire must be much larger and the apparatus will cost two to three times as much as an ordinary startor. A startor in which an adjustable shunt-field resistance is embodied will also cost about 100 per cent. more.

It may be as well to point out that rheostats are devices for converting electrical energy into heat. They must not be boxed-up in inaccessible places, and the fire risk must be carefully borne in mind.

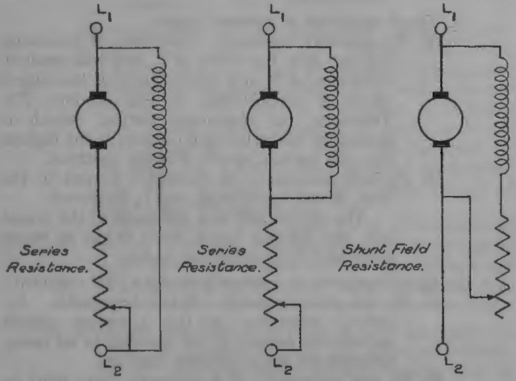

Fig. 71.

6. Speed regulation of D.C. motors.

i. *Shunt motors on constant voltage supply.*—The formulæ affecting these are :—

$$N \propto \frac{E_B}{\Phi} \propto \frac{V - I_A R_A}{\Phi}.$$

$$T \propto \Phi I_A.$$

$$P \propto TN.$$

It follows from these formulæ that the speed of a D.C. motor may be varied :—

(*a*) By varying the voltage applied to the armature (Φ remaining constant). A reduction of voltage reduces the speed below the normal and is usually carried out by inserting resistance in the armature circuit (Fig. 71 (*a*)).

(*b*) By varying the strength of the field. Inserting resistance in the field circuit reduces Φ and results in an increase of N above the normal (V being constant) (Fig. 71 (*c*)).

By normal speed is meant the speed with normal V and maximum Φ.

A common mistake is to connect resistances in the line, as shown in Fig. 71 (*b*). This reduces both E_B and Φ simultaneously, and there may be no appreciable alteration in the speed at all.

ii. *Speed regulation at constant torque.*

(*a*) *By armature resistance.*—Insertion of resistance will not alter the value of I_A, but will result in a decrease of N, and consequently of the output which is proportional to the product TN. Therefore, the maximum output (which is limited by the value of I_A) occurs at the highest (*i.e.*, the normal) speed, Φ being constant.

(*b*) *By field resistance.*—If resistance be put in the field, Φ will be reduced and I_A increased.

The output will be a minimum at the lowest (*i.e.*, the normal) speed, when Φ has its maximum and I_A its minimum value.

iii. *Speed regulation at constant output* (*i.e.*, TN constant).

(*a*) *By armature resistance.*—This is impossible. Inserting resistance in the armature circuit reduces the output of the machine in all cases, whereas the input remains constant.

(*b*) *By field resistance.*—If N increases, there must be a corresponding reduction in T. Neglecting efficiency, VI_A is constant, whence I_A is constant and T is proportional to Φ, *i.e.*, the load torque must be reduced in proportion to the increase in field strength.

iv. *Comparison between the armature-resistance and field-resistance methods of speed regulation.*

(*a*) *Relative first-cost of machine.*—For a given rated H.P. and range of speed, the motor designed for field regulation will be the larger and more expensive machine.

(*b*) *Relative efficiency.*—*Regulation by armature resistance* is a very inefficient method, and *should* therefore *not be used* except where unavoidable on grounds of expediency. The efficiency is not appreciably affected by changes in field strength, and this method should almost invariably be adopted in ordinary workshop practice.

(*c*) *Relative stability.*—The inherent speed regulation is not appreciably affected by reasonable changes in field strength ; but when a resistance is in series with the armature, every change in the value of the load torque will cause an appreciable speed variation. Therefore, the armature resistance method should not be used where there is no attendant, if the load is at all unsteady.

v. *Speed regulation by brush displacement.*—Since a backward displacement of the brushes in a motor weakens and a forward displacement strengthens the field, it is possible to vary the speed by simply shifting the brushes. In machines of ordinary construction, small changes of speed only are possible in this way, the limit being imposed by sparking, but if the machine is fitted with interpoles (*see* sub-para. vii), quite large ranges of speed variation can be obtained.

This method is not used to any great extent at present with D.C. machines except sometimes to make fine adjustments, but its possibilities are well worth bearing in mind. Some designs of A.C. commutator motor employ the method extensively.

vi. *Speed regulation on 3-wire system.*—If the field of a motor be connected across the outers of a 3-wire system, two economical running speeds can be obtained, the higher speed with the armature connected across the outers and the lower with the armature connected between the outer and the midwire. The speeds so obtained will be 2N and N, and the B.H.P. 2P and P, respectively. Most supply companies, however, limit the size of motor that may be controlled in this way to about 10 H.P.

vii. *Possible range of speed variation by field resistance.*—In machines of ordinary design without interpoles, which are worked on the knee of the magnetization curve, the range of speed variation possible by altering the strength of the field is limited to about 15 per cent. If more is attempted, the effects of armature reaction may introduce commutation difficulties.

It is desirable from a commutation point of view always to have a large ratio of field to armature ampere-turns, and this is specially necessary if a large range of speed regulation is required. This usually means a relatively large field magnet system of high permeability, to enable a high flux density to be employed with the iron well below saturation. Moreover, the armature coils should have a smaller inductance (and, therefore, fewer turns per coil) than the constant speed machine. This requirement necessitates a larger number of individual armature coils, each with fewer turns, and, therefore, a larger number of commutator segments, resulting in a larger commutator.

It follows that, to obtain satisfactory operation, a variable speed machine must be relatively large and expensive.

A speed variation of about 3 to 1 can be obtained if the precautions indicated above are observed in the design.

Modern machines, however, except in quite small sizes, are invariably fitted with interpoles which tend to neutralize armature reaction, and this naturally permits a much larger range of speed regulation. Ranges of 5 to 1 are quite practicable with ordinary interpole designs, but with compensating windings and a little compounding to ensure stability, ranges of 8 to 1 can be provided.

viii. *Possible range of speed variation by armature resistance.*—Since with this method both Φ and I_A are constant, armature reaction will not impose any limit, and all speeds are possible from crawling speed upwards. This is only true, however, if the load torque is constant.

If the load torque increases appreciably when the speed is very small, the machine may stop.

Increase of torque with constant Φ means an increase of I_A and, therefore, of I_AR_A (the ohmic drop), R_A being the total resistance of the circuit. When I_AR_A is equal to the supply voltage there can be no motion of the armature.

ix. *Rated torque and B.H.P. at various speeds.*—In all cases the maximum electrical input is fixed by the rating, and the field losses are relatively small. We have, therefore, approximately—

(*a*) *Field control*—

(i) Rated B.H.P. constant.

(ii) Rated torque *inversely* proportional to speed.

(*b*) *Armature control*—

(i) Rated B.H.P. directly proportional to speed.

(ii) Rated torque constant.

7. Compound motors.—i. *Differential winding.*—If an ordinary compound wound generator is run as a motor without change of connections, the magnetic effect of the series winding is opposed to that of the shunt, and for this reason this type of motor is termed a ***differential*** compound motor.

Literally it is the true compound motor, since the series coil, by weakening the field with increase of load, tends to compensate for the small fall in speed which occurs in the plain shunt machine due to armature resistance drop. By suitably selecting the ampere-turns of the series coil, an absolutely constant speed can be obtained between certain limits.

At first sight this would appear to be a very attractive type of motor, but it is in reality a treacherous machine. Unless the series coil is cut out at starting the machine may start up in the wrong direction, due to the fact that the series coil builds up more rapidly than the shunt. Moreover, if the machine is overloaded the series coil may become stronger than the shunt and tend to cause reversal. This reversal of direction of rotation results in excessive current and heavy mechanical strain, and may wreck the armature and the machinery connected thereto before the fuses or overload circuit-breakers act.

For these reasons, the differential compound motor is seldom used, the inherent speed regulation of the modern shunt machine being quite good enough for ordinary purposes.

ii. *Cumulative winding.*—The term ***compound*** winding, as applied to motors, is now invariably understood to mean a winding in which the series coils assist the shunt coils, so as to have a ***cumulative*** effect.

This arrangement gives the motor a speed-torque characteristic intermediate between those of the plain series and plain shunt machines.

It is a useful type of machine in cases where the load torque varies considerably throughout the cycle of operations, as in punching, shearing and planing machines, and in rolling mills. The series winding limits the demand on the power station by reducing the speed during the working stroke, and the shunt winding limits the speed during the return stroke. The *peak* power demand can be still further reduced by the addition of a flywheel, which would be almost useless with a plain shunt motor.

8. Running D.C. generators as motors.—Any D.C.

generator will run satisfactorily as a motor if certain elementary precautions are taken.

In the first place, it must be remembered that, to secure sparkless running, the brushes must *lead* in a generator and *lag* in a motor. Consequently, it will generally be found necessary to alter the position of the brushes when a generator is run as a motor; with interpole machines it may not be necessary to make any alteration.

i. *Series generator as motor without change of connections* (*see* Fig. 72).

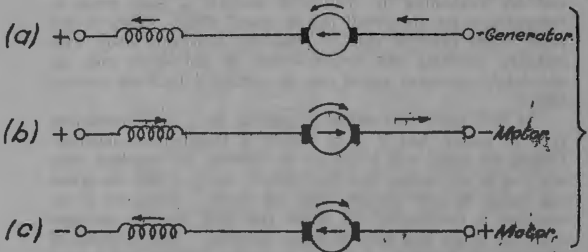

Fig. 72.

In Fig. 72 (*a*) the driving torque (in the direction of rotation) is assumed to be counter-clockwise, and, therefore, the electromagnetic *torque* due to interaction between the armature conductors and the field is *clockwise*. In Fig. 72 (*c*) the direction of current in both field and armature is the same as in Fig. 72 (*a*), whereas in Fig. 72 (*b*) the direction is reversed in both. Therefore the electromagnetic torque produced is in the same sense in all three cases. Consequently, if a series generator be run as a motor without change of connections, it will run in the direction *opposite* to that in which it was driven as a generator.

ii. *Shunt generator as motor without change of connections* (*see* Fig. 73).

Reasoning as in (i), it will be seen that if the directon of the electromagnetic torque be clockwise in Fig. 73 (*a*) it will be counter-clockwise in Figs. 73 (*b*) and 73 (*c*). Therefore a shunt generator will run in the *same* direction as a motor as it did when it was driven as a generator.

It will be observed that the polarity of the series winding in Figs. 74 (*b*) and 74 (*c*) is changed with regard to the shunt, *i.e.*, the machine becomes a differential compound motor, the disadvantages of which have been pointed out in para. 7.

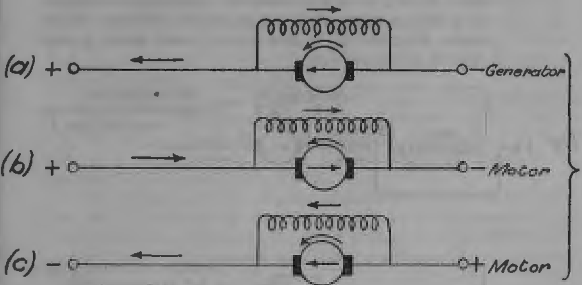

Fig. 73.

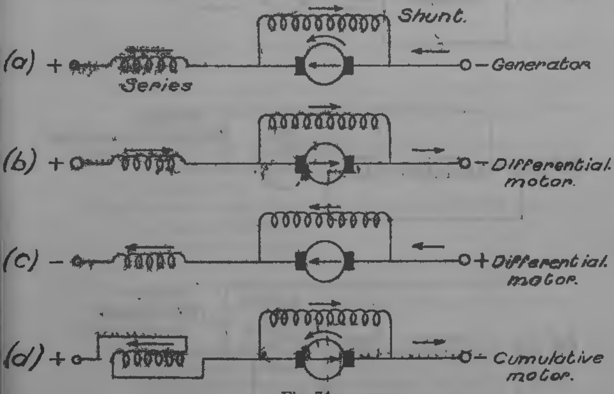

Fig. 74.

iii. *Compound generator as motor* (*see* Fig. 74).

In some cases the number of ampere-turns in the series winding of a compound generator is only about 5 per cent. of the number in the shunt winding, and for most purposes the machine will run quite satisfactorily as a shunt motor with the series coil cut out altogether.

If the series coil is used its connections must be changed so that it assists the shunt, as shown in Fig. 74 (*d*), in which case the machine becomes a cumulative compound motor, which will run in the *same* direction as a motor as it did when it was driven as a generator.

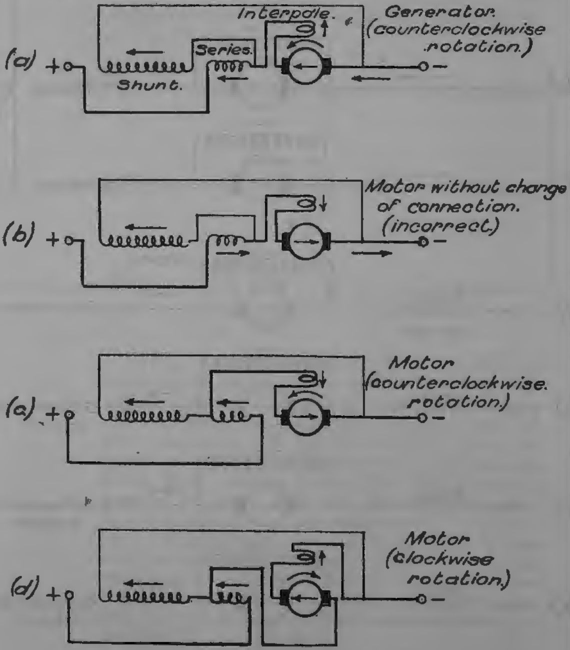

Fig. 75.

9. Reversing direction of rotation of D.C. motors.—To reverse the direction of rotation of a D.C. motor, either the direction of the armature current or the polarity of the magnetic field has to be reversed. If both be reversed simultaneously, the direction of rotation will obviously remain the same as before. Generally, it is better to reverse the connections of the armature, and it is specially important that shunt coils should not be frequently reversed owing to their high self-induction. However, when a motor is installed for a stationary drive and a final alteration of the connections is being made to secure the desired direction of rotation, it does not much matter whether it is the field or the armature connections which are changed.

Interpole windings must be treated as part of the armature.

Reversal of compound wound interpole motor (*see* Fig. 75).

Fig. 75 (*a*) shows the connections of a compound wound interpole generator in which the direction of rotation is assumed to be counter-clockwise.

Fig. 75 (*b*) shows the change of direction of current through the various coils, if the machine be, incorrectly, connected up for running as a motor of the same polarity without change of connections. The machine is now a differential compound motor.

Fig. 75 (*c*) and (*d*) show correct connections for running counter-clockwise and clockwise respectively.

90. *A.C. motors.*

1. **Types of A.C. motors.**—A.C. motors naturally fall under two main heads :—

i. *Synchronous motors*, which run at a constant speed proportional to the supply frequency and independent of the load.

ii. *Asynchronous motors*, which run at a speed varying somewhat with the load but usually less than that of synchronism.

Asynchronous motors may be further subdivided into :—

(*a*) Induction motors.
(*b*) Commutator motors.

Commutator motors may work by conduction or induction, and may have series or shunt speed-torque characteristics.

Any of these machines may be single-phase or polyphase, but 2-phase is seldom met with.

In general, single-phase machinery is inferior to polyphase.

2. **Synchronous motors.**—If an A.C. generator is supplied with power electrically, instead of being driven mechanically, it becomes a synchronous motor.

Speed.—So long as the supply frequency is constant, the motor speed will be ***absolutely constant*** for all loads within the range of the machine. If the speed is reduced, by overloading, below that of synchronism, the machine will stop. For some commercial purposes this constant speed is an advantage.

Starting.—Synchronous motors have *no inherent starting* *torque.* It is usual to run large machines up to synchronous speed by means of a small auxiliary induction motor (usually mounted on the main motor shaft), and then to synchronize in the usual way.

Small machines may be started up light, through auto-transformers, as induction motors, either by using the eddy currents induced in the rotor iron or by providing special squirrel-cage windings on the rotor.

The exciting windings can be used for this purpose, if they are subdivided and connected to a suitable resistance during the starting period. This type of machine *cannot* be designed to *start up* on appreciable load, and in this respect it is inferior to other types of A.C. motor.

Excitation.—A D.C. supply is required for the excitation of the field. This requirement in itself is usually sufficient to exclude this type of machine for general power work, requiring less than about 200 H.P., on account of the cost of the exciter.

Power factor.—As compared with induction motors, synchronous motors have the great advantage that their power factor is adjustable by field regulation and can be kept near unity at all loads. Their use for P.F. correction is dealt with in Sec. **34**, para. 9.

Direction of rotation.—The direction of rotation will be that in which the machine is started up before synchronizing. No alteration of connections is necessary to reverse the direction of rotation in the case of a single-phase machine. In 3-phase machines, two of the line wires must be changed over.

From the foregoing, it will be seen that the synchronous motor is not very suitable for military work, but, in view of the great importance of high power factor, it is necessary to keep an open mind and watch the commerical development of this machine. For the present, its use is chiefly confined to the motor side of an A.C.—D.C. converting set, where its high power factor and constant speed are desirable characteristics, where a D.C. supply is available for the excitation, and where it is not required to start up on load.

3. **Polyphase induction motors.**—This type of motor is so extensively used that its characteristics should be as well known as those of D.C. motors.

The machine may be considered as a special case of a transformer with an air gap in the magnetic circuit between the two windings, since there is no electrical connection between the stator and the rotor.

The rotor winding may consist of an ordinary insulated star-connected winding with the ends brought out to slip-rings (wound rotor construction), or of a number of un-insulated or lightly-insulated copper bars short-circuited by a ring at each end. (squirrel-cage construction).

The presence of the air gap, however, necessitates a relatively large magnetizing current and increases the inductive drop due to magnetic leakage; both these considerations reduce the P.F. of the machine. Whereas the no-load current of a transformer is only about 5 per cent. of the full-load value and its P.F. is 0·6 to 0·7, the no-load current of an induction motor is about 25 per cent. of the full-load value and its P.F. about 0·2 only.

The adverse effects of this air gap are more or less present at all loads, and the maximum P.F. of an induction motor seldom exceeds 0·85 in large machines at full load. Since the P.F. very largely depends on the length of the air gap, this type of motor is usually designed with an air gap as small as mechanical considerations will allow. Whereas D.C. machines have air gaps up to $\frac{1}{4}$ inch, induction motors seldom have air gaps greater than $\frac{1}{16}$ inch.

In the following explanation, the rotor current will invariably be referred to. In actual machines the rotor E.M.F. is always low, seldom greater than 200V, whereas the stator may be wound for any voltage up to 6,000V. However, a 1 to 1 ratio of voltages and currents will be assumed.

On this assumption, the stator current will always be somewhat greater than the rotor current, to provide for the magnetizing current and the stator iron and copper losses. The difference will, of course, become smaller as the load increases.

Since reactances and resistances cannot be dealt with arithmetically, the behaviour of A.C. machines will possibly be found more difficult to understand than that of D.C. machines.

4. Theory of polyphase induction motors.

i. *Fundamental quantities.*—

$$\left.\begin{array}{l}\text{Let } T = \text{total torque.}\\ \Phi = \text{total effective field flux.}\\ N = \text{speed in revolutions per minute.}\\ V = \text{applied voltage.}\\ P = \text{output in B.H.P.}\\ W = \text{input in watts.}\end{array}\right\}\text{As in D.C. machines (Sec. 89, para. 1).}$$

f = frequency of supply.
f_s = slip frequency.
R = rotor resistance.
L = rotor inductance.
X = rotor reactance.
Z = rotor impedance.
E_R = E.M.F. induced in rotor.
I_R = rotor current.
I_s = stator current.
θ = angle of phase difference between Φ and I_R.
ϕ = angle of phase difference between V and I_s.

ϕ will always be somewhat greater than θ owing to the magnetizing current, which is constant and equal to about 25 per cent. of the full-load current.

The quantities in one phase only will be considered.

Then $T \propto \Phi I_R \, Cos\ \theta$.
$E_R \propto I_R Z \propto \Phi f_s$ (approximately).
$P \propto TN$.
$W \propto VI_s \, Cos\ \phi$.

ii. *Starting current.*—As will no doubt be imagined from acquaintance with D.C. motors, the starting current of an induction motor, when switched directly on to the mains without limiting resistances, considerably exceeds the normal full-load value, if the rotor be short-circuited.

However, the effect of reactance (negligible in D.C. machines) keeps down the current, the maximum value of which does not exceed from 3 to 6 times the full-load value in ordinary machines. *Therefore, an induction motor is not liable to damage electrically by being switched directly on to the mains*, providing the machine starts in a reasonable time and is not excessively overloaded.

This is an advantage compared with D.C. machines, which, as explained in Sec. **89**, para. (iii), may take from 20 to 30 times full-load current at starting. Therefore, current-limiting resistances and low-volt protection are not necessary with induction motors, as far as the machine itself is concerned. But from the point of view of the line drop it is advisable to limit it, except in the case of very small machines. On ordinary town systems, the supply authorities usually insist that the starting current of machines exceeding about 5 H.P. shall not exceed full-load current. The practical methods adopted to limit the starting current are dealt with in para. 5.

iii. *Torque.*—Owing to the effects of reactance, the rotor current and stator flux are not in phase with one another, and, therefore, the torque with constant field is not directly proportional to I_R, as it is in D.C. motors, but to the product $I_R \, Cos\ \theta$. At full load the P.F. in the rotor is practically unity and the maximum torque per ampere is obtained. But at starting, although over three times full-load current may be taken, the P.F. is so low (about 0·35) that little more than full-load torque is developed.

Therefore, an induction motor is not liable to damage mechanically by being switched directly on to the mains.

iv. *Maximum torque.*—It can be shown that an induction motor develops maximum torque (*i.e.*, the product I_R *Cos* θ is a maximum) when the resistance R of the rotor is equal to its reactance (X or $2\pi f_s L$).

The resistance of the rotor windings is constant, but the reactance is directly proportional to the slip. When running normally on full load with a slip of 5 per cent., $2\pi f_s L$ is only from $\frac{1}{7}$ to $\frac{1}{10}$R in machines of ordinary design, and is, therefore, equal to R when the slip has increased to from 35 per cent. to 50 per cent. As may be supposed, the machine would be much overloaded with such a large drop in speed, but the maximum torque so exerted does not exceed about 2½ times full-load torque in commercial machines.

v. *Starting torque. Method of improving.*—At starting $f_s = f$, and, therefore, $2\pi f_s L$ has about 20 times its full-load value, and is from 2 to 3 times R. Consequently, maximum torque can be developed at starting if the total resistance of the rotor circuit is increased temporarily to about 2½ times the resistance of the rotor windings.

This increase of resistance is usually carried out by means of external resistances connected to the rotor windings through slip rings. The resistances are gradually cut out as the motor speeds up, since f_s falls with increase of speed, and the operation of starting is similar to that of starting a D.C. motor. Sometimes the necessary resistance is incorporated in the rotor and cut out by a centrifugal device when the machine speed has increased sufficiently. By suitably selecting the value of the added resistance, a starting torque of about 2½ times full-load torque can be obtained with about 2½ times full-load current at a P.F. of about 0·7. The increase of P.F. incidental to this increase of resistance is a very desirable effect. It is not, however, often necessary to produce such a large torque at starting, full-load torque usually being all that is necessary. This can be obtained with three times full-load current at a very low P.F., as explained above. It can also be obtained with full-load current only, but at a relatively high P.F., by adding resistance, a suitable value for which can be found as follows.

The problem is to arrange for the same conditions of P.F. and rotor current at starting as when running. Since $2\pi f_s L$ at starting is 20 times its value with 5 per cent. slip, the P.F. when starting will be the same as when running, if the total resistance of the rotor circuit is also increased to 20 times its value when running on load. Therefore, the value of the external resistance to be added should be about 19 times the resistance of the rotor.

It is the P.F. which is directly controlled in this way. It does not necessarily follow that the starting current will be equal to the normal full-load current, but it is approximately so in machines of ordinary design.

Therefore, adding resistance to the rotor windings at starting has three desirable effects :—

(*a*) It increases the starting torque per ampere.
(*b*) It reduces the starting current.
(*c*) It improves the P.F. of the starting current.

In the D.C. motor, the only function of the starting resistance is to limit the starting current.

vi. *Torque and speed. Inherent speed regulation.*—In D.C. machines the field is stationary and the armature speed, N, varies as $\frac{V}{\Phi}$, which is theoretically unlimited if Φ is reduced indefinitely (as it would be if the field circuit were broken).

In an A.C. polyphase induction motor, the *field rotates* at a definite speed $N = kf$, where k is a constant. This speed, known as the synchronous speed, is independent of both V and Φ. The actual mechanical speed of the rotor is always slightly less than this, to allow sufficient E.M.F. (E_B) to be induced for the $I_B Z$ drop in the rotor windings, but the *maximum speed* which the *rotor* can attain is that of *synchronous* speed. This is an advantage compared with D.C. motors, which race when lightly loaded if their fields are inadvertently reduced to a very small value.

Now $T \propto \Phi I_B Cos\ \theta, I_B = \frac{E_B}{Z}$ and $Cos\ \theta = \frac{R}{Z}$,

hence $T \propto \frac{\Phi E_B R}{Z^2} \propto \frac{\Phi E_B R}{R^2 + (2\pi f_s L)^2}$

Under normal running conditions, $E_R \propto \Phi f_s$ and $2\pi f_s L$ is small compared with R. Neglecting $2\pi f_s L$ and assuming $\Phi \propto V$, then, by substitution and reduction,

$$T \propto \frac{\Phi^2 f_s}{R} \propto \frac{V^2 f_s}{R},$$

which is a very important result.

Since R is constant, the *torque* which a motor will develop at a given speed is *directly proportional* to the *square* of the *supply voltage.*

Conversely, if the torque (T) is constant, the slip (f_s) will be inversely proportional to the square of the applied voltage, *i.e.*, the actual speed ($f - f_s$) of the rotor will fall if the supply voltage is reduced, although the synchronous speed will be unaffected. These effects are worth noting in cases where it is proposed to work induction motors on voltages lower than those for which they are designed. Since it is the slip which is inversely proportional to V^2, the actual percentage drop in speed is not so great as might be imagined at first sight.

Further, if both V and T are constant, $f_s \propto R$; therefore, the lower the resistance of the rotor windings the less will be the slip. Moreover, if R be increased by adding resistance externally, the slip will be correspondingly increased and the motor speed reduced.

Normally, however, V and R are constant. Then $T \propto f_s$ (it must not be forgotten that this is only true for small values of f_s), and, therefore, the drop in speed varies with the load. Now $f_s \propto \frac{E_R}{\Phi}$, Φ is constant, and E_R (or ZI_R) seldom exceeds 5 per cent. of V at full load; consequently, f_s varies from a negligible amount at no-load to about 5 per cent. at full load, and the actual speed is never less than 95 per cent. of synchronous speed at full load.

Therefore, the speed-torque characteristic of the A.C. induction motor is similar to that of the D.C. shunt motor (*see* Sec. **89**, para. 1 (vi)).

vii. *Relation between speed, frequency, and number of poles per phase.*—In a 2-pole motor, the rotor evidently makes one revolution per cycle; therefore, if f is the frequency, the synchronous speed will be f revolutions per second. If the motor has 4 poles, the rotor will make one revolution in two cycles, and will, therefore, only rotate at half the speed of the rotor of the 2-pole motor on the same frequency. Generally, if p is the number of poles and f the supply frequency, the synchronous speed of the rotor will be $\frac{2f}{p}$ revolutions per second or $\frac{120f}{p}$ revolutions per minute, *e.g.*, if $f = 50$ and $p = 4$, the synchronous speed

$$= \frac{120 \times 50}{4} = 1{,}500 \text{ r.p.m.}$$

These calculations refer to the number of poles in the resultant *rotating* field. When locating faults, it must be remembered that there are actually 4 fixed poles per phase.

A 6-pole machine will run at 1,000 r.p.m. on the same frequency of 50; if connected to a 25-cycle supply, it will run at half that speed. It will, however, generally take too large a magnetizing current to be of any practical use at the lower frequency.

Therefore, it follows that induction motors can only be designed for certain definite speeds, *e.g.*, on a 50-cycle supply, the synchronous speed of motors with 2, 4, 6, 8, and 12 poles will be 3,000, 1,500, 1,000, 750, and 500 r.p.m. respectively.

Since the actual frequency of a supply system is sometimes 2 or 3 per cent. above or below the declared frequency, the same variation in the speed of induction motors may be expected, irrespective of the variations due to load.

5. **Starting 3-phase induction motors.**—The problem of starting a 3-phase induction motor is quite different from that of starting a D.C. motor. The former is a much more robust and self-protecting type of machine than the latter. It cannot race, and only in exceptional circumstances can it burn out at starting. It may be definitely stated that, if it were not for the necessity for limiting the line disturbance, which is aggravated by the low P.F. of the somewhat large starting current, no startors at all would be necessary with induction motors, unless the motors are required to exert considerably more than full-load torque.

3-Phase squirrel-cage motors.—In view of the great simplicity of the squirrel-cage rotor, which requires no brushes or sliding connections, machines with squirrel-cage rotors should be used wherever practicable. Unfortunately, however, machines of ordinary design take 5–6 times full-load current to exert full-load starting torque.

No hard-and-fast rule can be laid down as to the largest machine which may be switched on without special starting arrangements, but in military systems, at any rate in emergencies, motors whose capacity is not greater than one-tenth that of the total connected load can be so started without undue line disturbance, especially if power and lighting mains are separate. From this point of view, it is a distinct advantage to have special mains for power purposes. Where power is purchased, the supplier will invariably decide the matter.

The following methods of starting squirrel-cage induction motors are given in order of inferiority :—

i. Direct starting with simple switch.
ii. Star-Delta connection.
iii. Auto-transformer or compensator.

i. *Direct starting.*—In permanent work this method is used with small machines only, up to about 5 H.P.

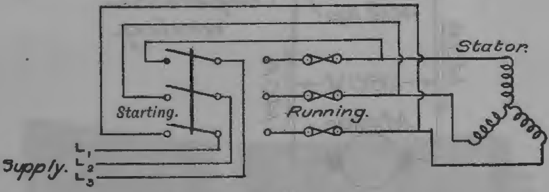

Fig. 76.

It is advisable to use 3-pole change-over switches, to enable the fuses or overload trips to be cut out at starting (*see* Fig. 76).

ii. *Star-Delta startor.*—When this method is used, both ends of each phase winding are brought out separately to the starting switch, which is provided with contacts so that the phases may be connected in star for starting and mesh for running.

In this case, the voltage across each phase winding is reduced from V to $\frac{V}{\sqrt{3}}$, the current in each line from I to $\frac{I}{3}$, and the torque from T to $\frac{T}{3}$. Consequently, this method also is only suitable for starting up light.

The switch should be interlocked, so that the mesh (running) position cannot be reached without going through the starting position.

Pl. **114** shows two views of a star-delta startor fitted with low-volt and two overload releases. Pl. **115** is a diagram of connections. As the overload trip coils are in circuit in the "starting" position, it may be necessary to fit "time lags" if the starting torque required is above about one-third of the full-load value.

iii. *Auto-transformer startors.*—The principle of this method is illustrated by Fig. 77, which shows the connections to one

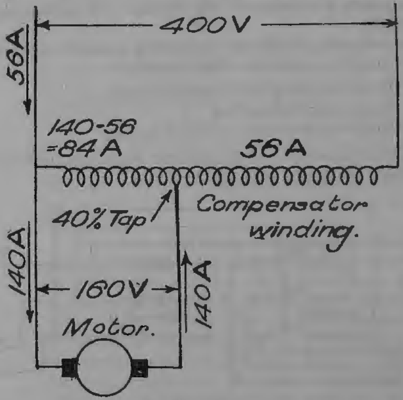

Fig. 77.

phase of the motor when the switch is in the starting position. The line disturbance with this form of startor is relatively less than with any of the three methods previously described. Auto-transformers are usually provided with several tappings, but the tapping, that has by trial been found most suitable, is permanently connected up.

Pl. **116** is an illustration of a type of auto-transformer startor suitable for wall mounting, in which the control contacts are immersed in an oil bath. Pl. **117** is a diagram of its connections. The overload relays are not in circuit in the starting position. It will be noted that the overload-release mechanism does not act directly on the switch mechanism but opens the circuit of the low-volt release coil.

The switch handle has three positions, "starting," "off," and "running," and is manipulated in the same way as the handle of a star-delta startor.

STAR-DELTA STARTOR.

(Air-break.)

Fig. 1.—General View.

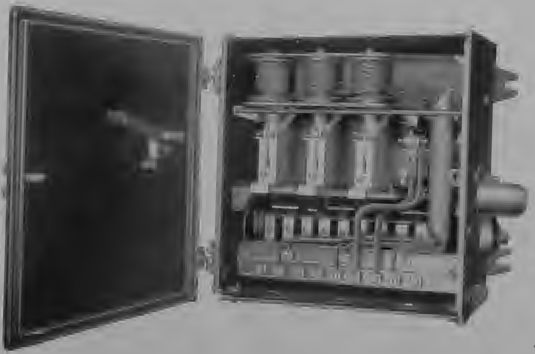

Fig. 2.—Cover Open.

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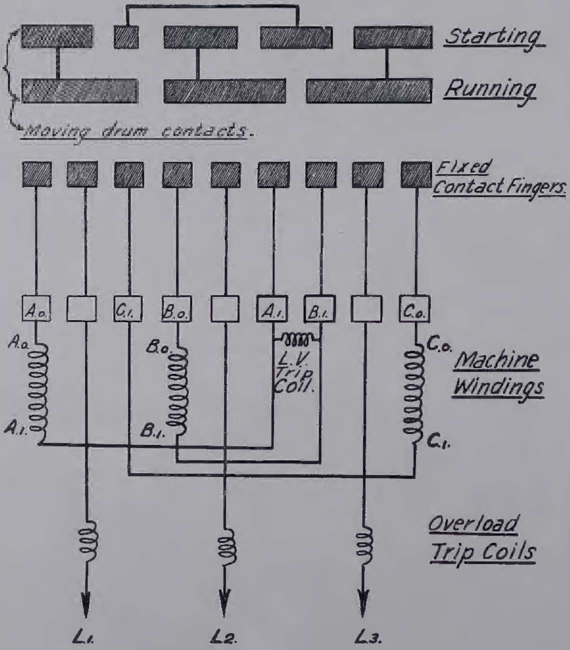
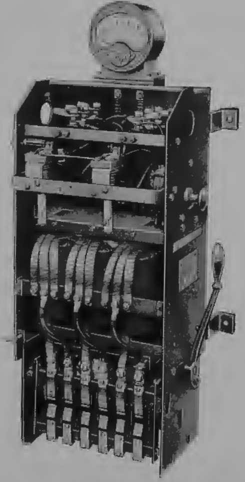
STAR-DELTA STARTING SWITCH.

Diagram of Connections.



AUTO-TRANSFORMER STARTOR.

(Oil-break).



Oil Tank and Front Cover removed

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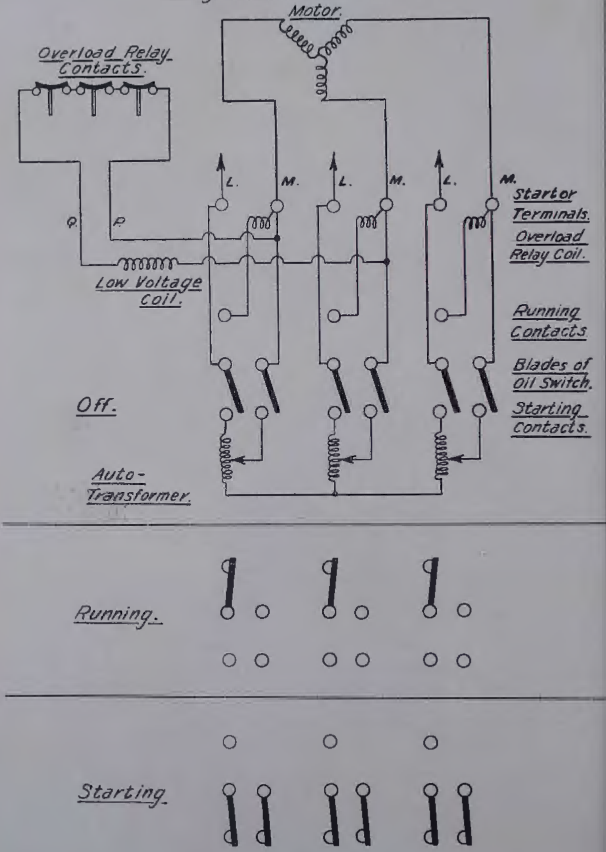
AUTO-TRANSFORMER STARTOR.

Diagram of Connections.



The handles of both auto-transformer and star-delta startors are so arranged that they have to be brought sharply from the " starting " through the " off " to the " running " position to prevent an appreciable drop in speed during the period of transition, when the power is cut off.

3-phase squirrel-cage motors with high starting torque.—A number of special designs of squirrel-cage rotors have been introduced which have starting characteristics superior to those of the ordinary design. It has been explained above that if resistance is added to the rotor windings the starting torque is improved, but unless the resistance is cut out when running, the efficiency and speed regulation will suffer. Motors with a centrifugal device to cut out the resistance when the speed reaches an appreciable value have been used to some extent, but are not often met with nowadays.

Another and more common arrangement is to provide two distinct squirrel-cage windings, one set of rotor bars being of relatively high resistance and placed in open slots near the periphery, and the other of low resistance placed at some distance below the high-resistance bars. The low-resistance winding being embedded in the iron has a much higher inductance than the other winding. When the supply is first switched on the frequency of the rotor current is 50, but under normal running conditions it is reduced to about 2 or 3 cycles per second. The high-resistance, low-inductance winding produces the main starting torque and the other winding the main load torque.

The advantage of this arrangement will be clear from the following table, showing the starting torque obtained under various conditions :—

A. **Ordinary squirrel-cage motor.**
    i. Direct Starting : 100 per cent. Full Load Torque with 5 times Full Load Current.
    ii. Auto Transformer Starting : 50 per cent. Full Load Torque with 2½ times Full Load Current.
    iii. Star Delta Starting : 40 per cent. Full Load Torque with 1¾ times Full Load Current.

B. **High torque squirrel-cage motor (double winding).**
    i. Direct Starting : 200 per cent. Full Load Torque with 3½ times Full Load Current.
    ii. Auto Transformer Starting : 100 per cent. Full Load Torque with 1¾ times Full Load Current.
    iii. Star Delta Starting : 70 per cent. Full Load Torque with 1¼ times Full Load Current.

These High Torque Motors are rather more expensive than the ordinary squirrel-cage type, but much cheaper than slip-ring motors.

3-phase slip-ring induction motors.—If it is not considered practicable to use a squirrel-cage motor, it will be necessary to use a motor with a wound rotor, in the windings of which external resistance can be inserted during the accelerating period. In this case, the stator is switched directly on to the mains with the rotor open-circuited. The machine then takes about 25 per cent. of the full-load current, which is practically all magnetizing current and nearly wattless. The rotor circuit is then closed through resistances, which are gradually cut out as the machine speeds up. The advantages of this method of starting have been fully dealt with in para. 4 (v).

Pl. **118**, Fig. 1, shows a simple form of face-plate starting rheostat without automatic features, and Pl. **118**, Fig. 2, gives a diagram of connections.

6. Protection of 3-phase induction motors.

Low voltage protection.—A low-voltage release is not absolutely essential with an A.C. motor startor as explained in para. 4 (ii), but it is a cheap and very desirable addition. One low-voltage release only is necessary.

Over-load protection.—It must be emphasized that one overload trip is insufficient. If all the electrical connections are correct, it will function satisfactorily on ordinary mechanical overload, but in the event of an electrical fault occurring on the other two phases it may not do so. Further, a 3-phase induction motor may run on and possibly continue to develop full-load torque with one of the line wires disconnected, provided that it is started up with all three wires connected normally. The machine will naturally take a much larger current on the two lines, and two of the phase windings (in the case of a star connected machine) will become dangerously overheated.

The same trouble is likely to arise when fuses are used for overload protection. If, as is usual with star-delta and autotransformer startors, the fuses are not in circuit at starting, the machine will start up all right and continue to run on when the startor is switched over to the " running " position with one fuse blown. For this reason, in addition to the other disadvantages of fuses referred to elsewhere, modern practice favours the installation of startors or circuit breakers with over-load trips for all 3-phase motors.

If fuses are used it is advisable to connect an incandescent lamp across each to indicate when it blows.

In the case of a simple 3-wire 3-phase supply with neutral insulated, two overload trips are sufficient, but if the neutral point is earthed, three over-load trips are necessary.

If the machine is liable to momentary overloads of short

STARTING RHEOSTAT FOR 3-PHASE SLIP-RING INDUCTION MOTOR.

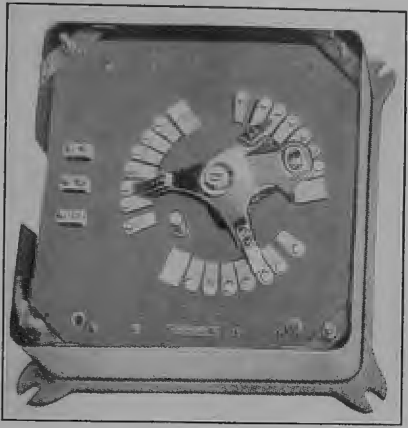


Fig. 1.—General View. (Cover and Handle removed.)

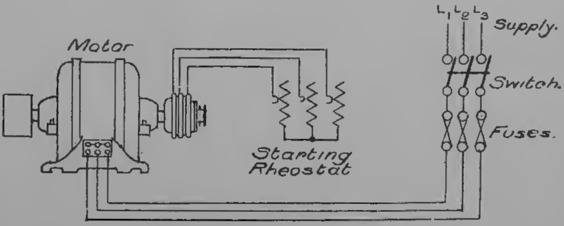


Fig. 2.—Diagram of Connections.

[Fig. 1 reproduced by permission of The British Thomson-Houston Co., Ltd.

duration, time lags should be fitted to the overload trips (*see* Sec. **13**).

7. Speed regulation of induction motors. — The synchronous speed of an induction motor $= N = 120\frac{f}{p}$ revolutions per minute (*see* para. 4 (vii)) and can be varied by altering the value of f or p.

i. *Speed regulation by altering number of poles.*—It is not practicable to alter the frequency, but satisfactory multispeed machines are obtainable in which 2, 3, or 4 definite running speeds can be obtained by varying the number of poles. This is, in effect, an electrical method of changing gear.

Two-speed motors of this type have comparatively simple connections, but, if a greater number of speeds is provided for, the connections become somewhat complicated.

This is a very efficient method of speed regulation (*see* Pl. **119**), and the starting torque is sensibly the same at each speed.

At constant torque the output naturally falls in proportion to the speed, *i.e.*, a motor rated at 10 B.H.P. at 1,500 r.p.m. will develop 6·7 B.H.P. only at 1,000 r.p.m. and 5 B.H.P. at 750 r.p.m. Since the constant losses remain approximately the same at all speeds, there is a small reduction in efficiency and a large reduction in power factor at the lower speeds, since the machine is really running at a fraction of its rated full load. However, this reduction in efficiency and power factor is not greater than with an ordinary induction motor, which runs at constant speed and drives a load, through a gear box, at different speeds.

The multispeed machine is preferable from a mechanical point of view. It is naturally much more expensive than the constant speed machine, but the difference in cost is not great when the cost of the mechanical gear box is added to that of the constant speed machine.

ii. *Speed regulation by Cascade connection.*—If two similar induction motors are mechanically coupled together, two definite speeds can be obtained in the following manner.

If the stators of both machines are connected to the supply, as in Fig. 78 (*a*), the maximum speed will be obtained, corresponding with the supply frequency and the number of poles in each machine; but if the stator of one machine is disconnected from the supply and short-circuited and the rotors are connected together, as in Fig. 78 (*b*), then the combination will run at half the former speed.

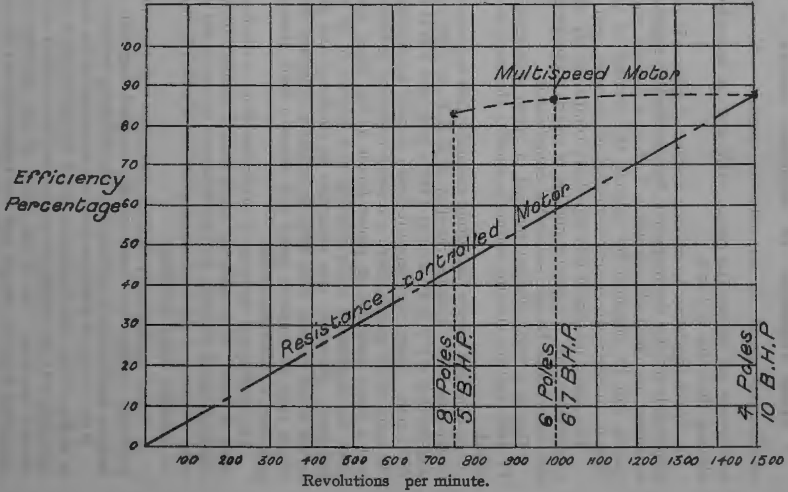
This is also a very efficient method of obtaining two running speeds.

The Cascade method of control is largely used in traction

PLATE 119.

EFFICIENCIES OF A.C. MOTORS.

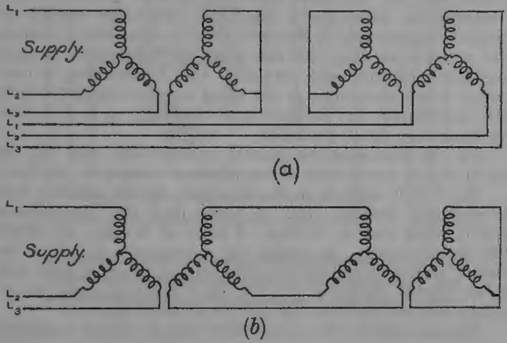
Constant Full-load Torque at all Speeds.



and crane work. It corresponds very closely with the series parallel control of D.C. series motors.

iii. *Speed regulation by rotor resistance.*—The effect of adding resistance to the rotor windings was explained in para. 4 (vi).

This method is similar to that of inserting resistance in series with the armature of a D.C. motor and has the same disadvantages (*see* Sec. **89**, para. 6). This method, therefore, although giving any desired change of speed, is very inefficient. Pl. **119** illustrates how the efficiencies of multispeed motors and resistance controlled motors vary with the load.



(a)

(b)

Fig. 78.

iv. *Combination of method (iii) with method (ii).*—A combination of methods may be employed with advantage in certain circumstances, method (ii) being used to obtain the large variations and method (iii) the small ones. Flexibility in speed is then attained without too great a sacrifice from the efficiency point of view.

v. *Speed regulation by use of commutator.*—It will be realized from the above that the ordinary polyphase induction motor, although possessing many excellent features, is not a variable speed machine like the D.C. shunt motor, in which the speed can be gradually and economically varied. For this reason, several types of polyphase commutator motor have been introduced. The addition of a commutator causes the motor to lose much of its simplicity from a mechanical point of view, and, up to the present, its relatively high initial cost and maintenance charges have prevented it from being extensively adopted, except in a few special industries, *e.g.*, textile, printing, and paper-making. The most common type will be briefly described.

The 3-phase shunt commutator motor.—In a D.C. shunt motor, an alteration in speed may be effected by varying the armature P.D. either (i) by means of a variable voltage supply, or (ii) by a series resistance. In the ordinary slip-ring induction motor, method (ii) only is available, but in the commutator motor method (i) is possible.

The machine has the usual stator and rotor; the stator, however, carries the secondary winding and the rotor the primary winding, and herein lies one difference between the motor and an ordinary induction motor. Another, and fundamental, difference is that the rotor also carries an ordinary lap winding in the same slots as those which contain the primary winding, the two windings being quite distinct and insulated from one another. This lap winding is connected to a commutator in the usual manner associated with D.C. machinery, and its function is to inject an E.M.F. into the secondary (stator) winding.

Fig. 79 illustrates the general arrangement, and Fig. 80 the electrical connections of one phase of a two-pole machine.

The E.M.F. induced in the secondary by the rotating field is naturally 3-phase, and in order that the commutator E.M.F. shall also be 3-phase, 3 pairs of brushes are fitted 120 degrees apart. To enable the commutator E.M.F. to be varied, arrangements are provided for one brush of each pair to be rotated clockwise and the other brush of each pair to rotate counter-clockwise (or *vice versa*) simultaneously.

The necessity for this arrangement may be simply explained as follows :—

Consider a 2-pole D.C. generator running at constant speed with the brushes in the axis of commutation. The E.M.F. will have a steady constant value. Now, with the armature speed remaining constant and the brushes fixed in position, imagine the field magnets to rotate slowly at, say, one revolution per second in the opposite direction. The E.M.F. at the brushes will then be alternating with a frequency of one cycle per second and a maximum value equal to the steady value generated when the field was stationary. In general, the *frequency* of the E.M.F. will be equal to the speed of rotation of the field, but the *value* of the E.M.F. will be independent of this speed and dependent only on the position of the brushes. If an arrangement is provided by means of which the brushes may be rotated towards each other, the E.M.F. between them will naturally be reduced and will fall to zero when the brushes are in line on the same commutator segment.

In an ordinary induction motor, the rotor turns in the same direction as the field, but in the 3-phase commutator machine, as the primary winding is on the rotating element, the latter turns counter-clockwise if the field rotates clockwise, and *vice versa*. In the case of a 2-pole machine, if f is the frequency of supply and n the speed of the rotor in revs. per second counter-clockwise, the speed of the rotating field is

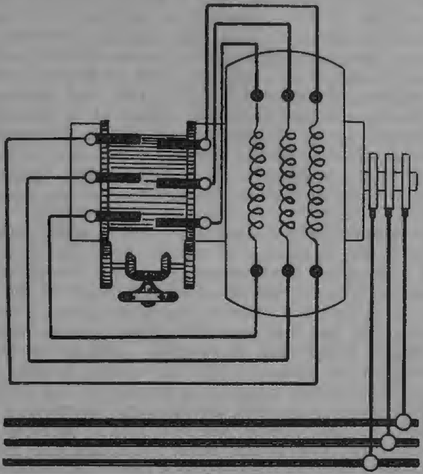


Fig. 79.

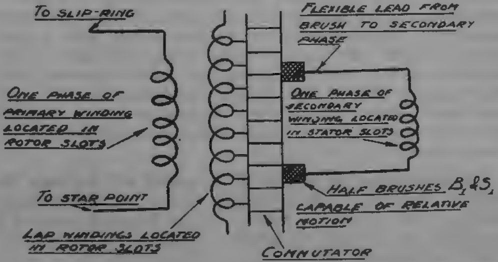


Fig. 80.

f revs. per second clockwise relative to the rotor conductors, and $(f - n)$ revs. per second clockwise relative to the brushes and the secondary (stator) winding. The frequency of the E.M.F. *induced* in the secondary is therefore exactly equal to that of the E.M.F. *generated* in the lap winding. At synchronous speed $f = n$, and then the field is stationary in space and there is no E.M.F. induced in the secondary. When the two brushes (of each pair) are in line on the same commutator segment the injected E.M.F. is zero, and the machine runs as an ordinary induction motor at a little below synchronous speed, the induced voltage in the secondary being just sufficient for the impedance drop due to the load current in the secondary. Assuming constant torque this current will also be constant (or nearly so) in magnitude and direction.

If the brush pairs are now separated in such a direction that an E.M.F. is injected of opposite phase to the induced E.M.F., the latter must increase, and this necessitates an increase of $(f - n)$, and therefore a decrease of the rotor speed n. If, on the other hand, the brush pairs are brought back into line and then separated in the opposite direction, the injected E.M.F. will be reversed. And it will now be necessary for the induced E.M.F. to decrease in value if the current is to remain constant in magnitude and direction. To effect this $(f - n)$ must decrease and, therefore, n must increase. As the reverse injected E.M.F. increases, the induced E.M.F. falls to zero when $f = n$, and then reverses in sign when the rotor speed exceeds that of synchronism.

The motor is started and controlled simply by moving the brushes. The usual designs provide for a speed regulation of 1–3, 50 per cent. above and 50 per cent. below synchronous speed, *e.g.*, a 6-pole machine at 50 cycles would have a speed range from 500–1,500 r.p.m. With $1\frac{1}{2}$ times full-load current, a starting torque of twice the full-load value is obtained with motors up to 25 H.P., and $1\frac{1}{2}$ times full-load value with larger machines. The efficiency is not so good as that of the plain induction motor and the power factor is rather poor at the lower speeds.

8. **Reversing direction of rotation of 3-phase induction motors.**—This is simply carried out by changing over any two of the line wires. Where frequent reversal is necessary, it is usual to install a double-pole change-over switch, as shown in Fig. 81.

9. **The single-phase induction motor.**—This type of machine may still be met with in small sizes. It is much used for ceiling fans. On load its behaviour is very similar to that of the polyphase induction motor, but *it is inferior*

in every respect, as shown by the following representative figures for 15 B.H.P. motors :—

——	Maximum starting torque (times full load).	Full-load P.F.	Full-load efficiency.	Weight, cwts.	Cost.
Single-phase ..	⅓	0·80	0·80	10	1·4P
3-phase ..	2½	0·85	0·87	6	P

Whereas the polyphase motor is self-starting, the single-machine is not, unless provided with auxiliary or special windings.

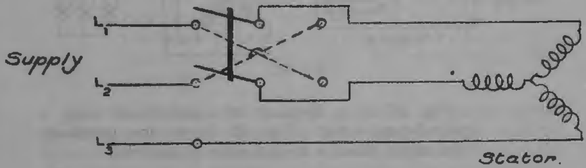


Fig. 81.

The two most common methods of making the machine self-starting are as follows :—

i. *Split-phase method of starting single-phase induction motors.*—In this method, an auxiliary or starting winding is provided on the stator in the position which would be occupied by the second winding if the machine were wound for a 2-phase supply. The main and starting windings are connected in parallel. If the currents in the two windings were 90° out of phase, a true 2-phase rotating field would be obtained. Such a large phase difference cannot be obtained practically, but, by means of resistance or inductance, the time phase difference between the currents in the two windings can be made large enough to enable the motor to start light or develop about one-third full-load torque.

It was formerly the practice to add inductance to the starting winding, but now condensers are sometimes used instead ; some engineers put in resistance only, reasoning that, since both windings possess considerable inductance in themselves, the necessary phase difference can be obtained by reducing the angle of lag in one coil.

The auxiliary winding need not be of such large wire as the main winding, as it is only in use during the starting period. When the motor has attained nearly full speed, the starting winding is switched out of circuit. The rotor may be squirrel-cage or wound. If the latter, it is usually wound 3-phase and provided with an ordinary 3-phase starting rheostat.

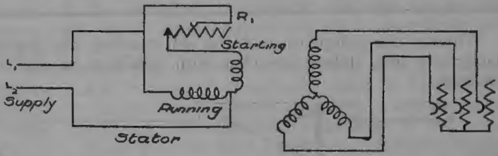


Fig. 82.

Fig. 82 is a diagram of connections using a squirrel-cage rotor. Fig. 83 shows the necessary connections when a wound rotor is provided.

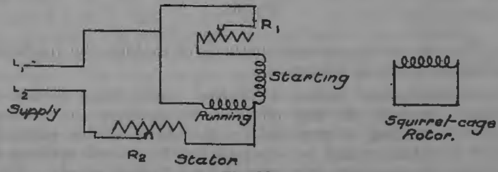


Fig. 83.

ii. *Pole changing method of starting single-phase induction motors.*—Messrs. Crompton Parkinson make a single-phase induction motor which develops a starting torque three times that of the ordinary type with squirrel-cage rotor and twice that of the ordinary type with wound rotor

In the case of a four-pole machine, this result is obtained partly by connecting the stator windings so as to produce a six-pole field at starting, and partly by increasing the effective resistance of the rotor windings when the field is six-pole, this change of resistance being made possible by the use of simple connector bars in place of one of the rotor end rings.

The machine is rather more expensive than the ordinary type, but much cheaper and more robust than the commutator type. Its efficiency and power factor are equal to that of the ordinary type.

iii. *Commutator method of starting single-phase induction motors.*—If the rotor is provided with a commutator and windings similar to the armature of a D.C. motor.

A starting torque considerably greater than full-load torque can be obtained if desired. When the machine approaches synchronous speed the commutator segments are short-circuited either by hand or by an automatic centrifugal device, and the machine continues to run as a single-phase induction motor with squirrel-cage rotor.

With this method of starting the ordinary D.C. type of startor is used, but it is advisable to use a resistance of greater carrying capacity for an A.C. motor than is required for a D.C. motor of the same horse-power.

10. **Reversing direction of rotation of single-phase induction motors.**—When the split-phase method of starting is used, it is simply necessary to reverse the connections of the auxiliary starting winding. When starting as a commutator motor, reversal is carried out by shifting the brushes to a corresponding position on the other side of the stator axis.

11. **Single-phase commutator motors. General considerations.**—Owing to the many drawbacks of the single-phase induction motor, considerable attention has been given to the development of single-phase commutator motors, with characteristics similar to those of D.C. motors, and suitable either for traction or for industrial purposes. Various types, which fulfil these conditions and which are very little inferior in performance to D.C. machines, have been developed.

12. **Single-phase commutator motors with series characteristics.**—If an ordinary D.C. series motor be connected to an A.C. supply, it will rotate and exert a unidirectional torque, since the polarities of both armature and field change at the same instant. The speed-torque characteristic will be similar to that obtained when supplied with D.C., but the performance will not be satisfactory for the following reasons :—

i. The field magnets will become unduly heated.

ii. There will be destructive sparking at the brushes, since the short-circuited coils undergoing commutation at any instant act as the secondary of a transformer linked with the field flux and the latter is constantly changing in value.

iii. The power factor will be very low on account of the highly inductive field and armature circuits.

13. **Single-phase commutator motors with shunt characteristics.**—An ordinary D.C. shunt motor will not exert any appreciable torque if it is connected to an A.C. supply. Whereas the armature current will be nearly in phase with the applied voltage the field current will be very small and nearly 90° out of phase, and, therefore, the torque (*see* para. 4 (iii)) will be negligible.

Further, the field magnets would quickly heat up, due to excessive eddy current and hysteresis losses.

Satisfactory A.C. commutator motors with shunt characteristics can be obtained, however, though they are very expensive.

14. For these reasons, all types of A.C. commutator motors have a laminated field system, a distributed stator field winding instead of salient poles, a uniform and relatively small air gap, a low ratio of field (stator) to armature (rotor) ampere-turns, and a much greater subdivision of the armature winding as compared with D.C. machines. The latter necessitates a much larger number of commutator segments, and, consequently, a commutator of comparatively large diameter. The brushes are of fairly high resistance carbon and bridge two commutator segments only, whilst an extra resistance is frequently added between the armature, or rotor, windings and the commutator segments. Single-phase A.C. motors are, therefore, more costly and less efficient than D.C. machines of equal output, but the former have the advantage in the matter of weight.

Table V summarizes these qualities.

TABLE V.—*Comparison between D.C. and single-phase A.C. commutator motors.*

Type of motor.	Cost.	Weight.	Efficiency at full load.	Remarks.
D.C.	P	W	E	—
Single-phase A.C. commutator from	P	0·8W	0·94E	According to size
to	1·2P	0·9W	0·96E	

91. *Rating of motors.*

The rating and performance of the majority of the electric motors, both A.C. and D.C., likely to be met with in the Service are specified in B.S.S. 168, the British Standard Specification for the Electrical Performance of Industrial Electric Generators and Motors with class A insulation (*i.e.*, cotton, silk, paper, or enamel).

Based upon B.S.S. 168, two Government Department Electrical Specifications have been issued :—

i. G.D.E.S. No. 2 for D.C. Motors from 1 to 100 B.H.P.
ii. Ditto 15 for A.C. ditto

These specifications divide machines into three classes, viz. :—

Class 1.—Motors operating under conditions of service as stated in B.S.S. 168, *i.e.*, when the cooling air temperature does not exceed 30° C.

Class 2.—Motors operating under conditions where the cooling air temperature is above 30° C., but does not exceed 45° C.

Class 3.—Motors operating in tropical climates or abnormal temperature conditions, when the cooling air temperature exceeds 45° C., but does not exceed 55° C.

In the succeeding paras. of this section references are made to B.S.S. 168, but it should be understood that for W.D. purposes the more stringent G.D.E.S. must be complied with as well.

2. **Safe working temperatures.**—From the electrical point of view, the output of a machine is limited chiefly by the maximum temperature which the insulation can withstand without deterioration. A certain percentage of the input is used up as heat in the machine itself, but, as long as this heat is being dissipated fast enough to prevent the temperature of the windings, &c., from exceeding the safe working value, the machine may be considered to be working within its capacity. Consequently, any artificial method of increasing the rate of cooling, such as a fan, will enable the H.P. rating to be increased.

B.S.S. No. 168 specifies that the limits of maximum temperature laid down by the International Electrotechnical Commission (I.E.C.) should in no case be exceeded. This means a maximum permissible temperature of 90° C., when measured by thermometer, for windings and the cores with which they are in contact, and, in general, the same limit for commutators and slip rings ; for full information, reference should be made to the I.E.C. Publication No. 34.

B.S.S. No. 168 also specifies that the temperature rise of machines shall not exceed the limits given in Table **W**.

TABLE **W**.—*Limits of temperature rise for electrical machines.*

Part of machine.	Temperature rise (measured by thermometer).	
	Machines (other than totally enclosed) having a continuous rating.	Machines having a short-time rating, and totally enclosed machines.
	°C.	°C.
Windings insulated with Class A material and cores with which they are in contact	40	50
Commutators	45	55
Slip rings, open type ..	45	55
Slip rings, enclosed type ..	55	55
Uninsulated parts, including cores not in contact with insulated windings.	The temperature rise shall in no case reach such a value that there is risk of injury to any insulating material on adjacent parts.	

The I.E.C. Rules call for the measurement of temperature rise by the resistance method under certain conditions, but it is considered that, for the class of machine dealt with in B.S.S. 168, measurement by thermometer is satisfactory.

It will be noted that a motor which just complies with the figures given in Table **W** would exceed the maximum of 90° C. if the air temperature were greater than 40° C. It follows, therefore, that a machine installed in the tropics will usually have to be larger for a given load than would be necessary in England.

3. **Effect of " time-element."**—Since the heating effect varies as I^2Rt, it is clear that the time taken for a machine to reach a certain temperature will be inversely proportional to the square of the load current. This so-called *Time-element* is not sufficiently appreciated, as a rule, and, consequently, motors are often selected that are too big for their work.

Consider a ventilating fan requiring, say, 10 H.P. and a crane which also requires 10 H.P. when lifting its maximum load. The fan may be required to run continuously night and day for long periods, whereas the crane will probably work at full load for short periods only and then run light or remain idle for long intervals.

It will be unnecessary to install such a large motor for the crane as for the fan, since the average rate of heat generation in the former will be much less than in the latter. During the periods of maximum load, heat is generated in the smaller machine at a greater rate than it can be dissipated, but the thermal capacity of the machine acts as a reservoir.

B.S.S. No. 168 recognizes two classes of rating, viz. :—

i. *Continuous rating.*
ii. *Short-time rating.*

The British Standard Continuous Rating defines the load which can be carried for an unlimited period without exceeding the limits of temperature rise.

The British Standard Short-time Rating defines the load which can be carried for the time specified in the rating without exceeding the limits of temperature rise. For general purposes two standard short-time ratings are recognized, viz. :—(*a*) *One hour rating*, and (*b*) *One half-hour rating*.

When the class of rating is not specified it should be understood that the machine is intended for continuous service.

These ratings do not, however, cover every possible case.

A crane motor is rarely required to work at full load for half an hour, and might well be even smaller than would be necessary to comply with the half-hour rating given above.

4. Types of machines. Effect of type on rating.—B.S.S. No. 168 recognizes 11 distinct types of machine, viz. :—

i. Open pedestal machine.
ii. Open end-bracket machine.
iii. Protected machine.
iv. Enclosed ventilated machine.
v. Machine with fine mesh covers.
vi. Totally enclosed machine.
vii. Pipe-ventilated machine.
viii. Forced draught machine.
ix. Induced draught machine.
x. Drip-proof machine.
xi. Flame-proof machine.

An *Open Pedestal Machine* is one which has pedestal bearings, supported independently of the machine frame, and in which there is no restriction to ventilation other than that necessitated by good mechanical construction.

An *Open End-Bracket Machine* is one having end-brackets, of which the bearings form an integral part, in which there is no restriction to ventilation other than that necessitated by good mechanical construction.

A *Protected Machine* is one in which the internal rotating parts and live parts are protected mechanically from accidental or careless contact, while ventilation is not materially obstructed. Unless otherwise specified, a protected machine has end-bracket (end shield) bearings.

An *Enclosed Ventilated Machine* is one in which the ventilating openings in the frame are protected with wire screen, expanded metal, or other suitable perforated covers, having apertures not exceeding ½ sq. in. (3·2 sq. cm.) in area, but not less than $\frac{1}{50}$ sq. in. (0·13 sq. cm.) in area.

Machines with Fine Mesh Covers, having openings smaller than $\frac{1}{50}$ sq. in. (0·13 sq. cm.) in area, shall be regarded as totally enclosed machines. They shall comply with this Specification when the machine is tested with the openings closed, as such openings frequently become clogged in actual service.

A *Totally Enclosed Machine* is one so enclosed as to prevent circulation of air between the inside and outside of the case, but not sufficiently to be termed "air-tight."

The Specification, also, subdivides motors which do not run at one constant speed into :—

i. Change speed motors.
ii. Variable speed motors.
iii. Inverse speed motors.

The rating of a machine of given size will depend upon its type. For example, a totally enclosed motor, having very much less capacity for heat dissipation than an open type one, needs to be considerably larger for a given output.

To take the two extremes, the smallest and cheapest motor of a given speed and B.H.P. rating will be the open type for intermittent working in this country, and the largest and most expensive will be the totally enclosed type for continuous working in tropical climates.

5. Overload capacity.—It is common knowledge that electrical machines are much more elastic to overloads than prime movers, especially I.C. engines.

B.S.S. No. 168 specifies that motors (other than single-phase motors) shall be capable of sustaining, without injury, the overloads given below, *after* having attained the temperature rise corresponding to continuous operation at full load.

Motors with Continuous Rating (not totally enclosed) :—

25 per cent. overload in torque for 2 hours for sizes of 10 H.P. and upwards per 1,000 r.p.m.

25 per cent. overload in torque for half an hour for sizes below 10 H.P. per 1,000 r.p.m., and down to 4 H.P. per 1,000 r.p.m.

25 per cent. overload in torque for 15 minutes for sizes below 4 H.P. per 1,000 r.p.m., and down to 1 H.P. per 1,000 r.p.m.

Generators with Continuous Rating (not totally enclosed) :—

25 per cent. overload in current at full rated volts for 2 hours for sizes of 7½kW if D.C., or K.V.A. if A.C. and upwards per 1,000 r.p.m.

25 per cent. overload in current at full rated volts for half an hour for sizes below 7½kW if D.C., or K.V.A. if A.C. per 1,000 r.p.m., and down to 3kW if D.C., or K.V.A. if A.C. per 1,000 r.p.m.

25 per cent. overload in current at full rated volts for 15 minutes for sizes below 3kW per 1,000 r.p.m. if D.C., or K.V.A. if A.C., and down to 1kW per 1,000 r.p.m. if D.C., or K.V.A. if A.C.

Machines with Short Time Rating and all Totally Enclosed Machines are not capable of carrying sustained overloads.

For values of the momentary excess currents and torques permissible, reference must be made to the Standard Specification.

92. *Sizes and efficiencies of motors.*

1. **Efficiencies.**—Pl. **120** shows curves giving the average commercial efficiencies at full load of D.C. motors and A.C. induction motors from 1 to 100 H.P.

Pl. **121** gives two typical curves showing how the efficiency and power factor of a motor varies from no load to full load.

2. **Relation of speed to size, cost, and efficiency.**—D.C. motors can be designed to run at practically any speed. Taking advantage of this, there is sometimes a tendency to use abnormally low-speed motors in order to dispense with gearing or belting. It is, however, important to remember that an electric motor is essentially a high-speed machine, and that machines built for low speeds have relatively low efficiencies and are very expensive. It is, therefore, possible to carry the low-speed idea too far, and to lose more by the reduced efficiency of the motor than is gained by dispensing with gearing or belting.

A.C. motors can only be built to run at certain definite speeds, proportional to the supply frequency and the number of poles (*see* Sec. **90**, para. 4 (vii)). In this case also it is preferable to use high-speed motors on account of their superior efficiency and power factor.

For military purposes, when transport is an important consideration, the lighter weight of the higher speed machine is a great advantage. Moreover, the price of a motor varies approximately with its weight.

It is, however, just as necessary to guard against very high speeds as it is against abnormally low speeds, since the saving

PLATE 120.

EFFICIENCIES OF MOTORS.

Average Full-load Efficiencies of A.C. and D.C. Machines.

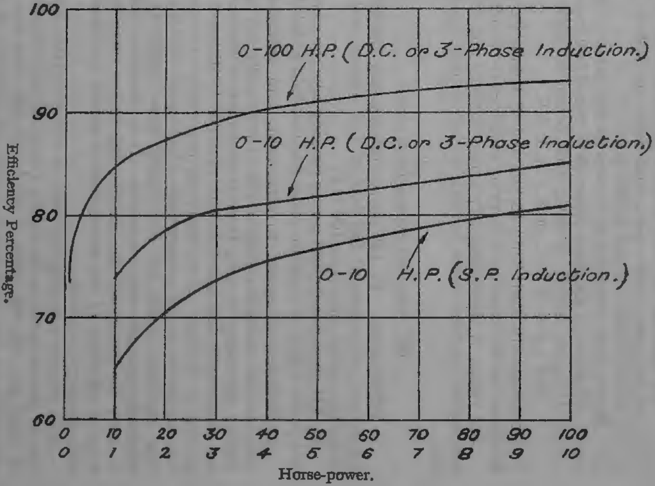
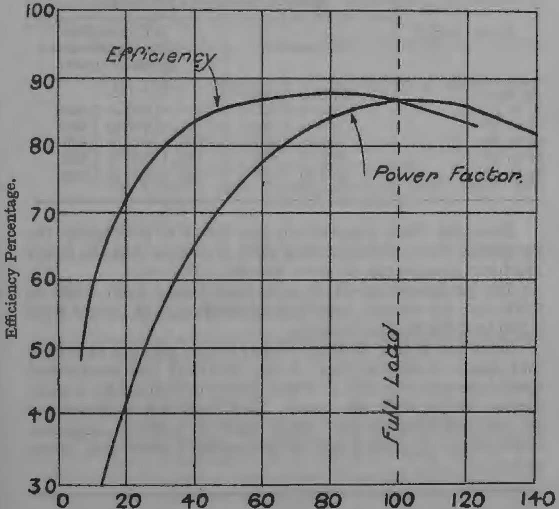


PLATE 121.

3-PHASE INDUCTION MOTORS.

Average Performance Curves of Machines from 15 to 25 h.p.



Percentage of Full Load.

in first cost is liable to be more than balanced by the increased cost of bearing maintenance, especially with belt drives. With D.C. machines, the commutator is liable to give more trouble at the higher speeds.

Direct-coupled machines with ball-bearings should always be used where exceptionally high speeds are desirable.

There are no standard motor speeds, but Table **X** gives some idea of the speeds most commonly met with in practice.

TABLE **X**.—*Speeds of motors.*

Size in B.H.P.	Speed in revolutions per minute.	
	D.C. motors.	A.C. induction motors (synchronous speed 50 cycles).
$\frac{1}{100}$ to $\frac{1}{10}$	2,500 to 3,000	—
$\frac{1}{10}$ to 1	1,350 to 2,000	1,500 or 3,000
1 to 10	1,000 to 1,350	1,000 or 1,500
10 to 20	800 to 1,000	750, 1,000, or 1,500
20 to 50	600 to 800	750, 1,000, or 1,500
60 to 100	400 to 600	750, 1,000, or 1,500

Since the limit imposed on the speed is principally the peripheral speed of the rotating part, it follows that the larger machines usually run at lower speeds.

The peripheral speed of armatures varies from 3,500 to 5,000 feet per minute, and that of commutators ranges from 1,500 to 2,500 feet per minute.

Since the B.H.P. is proportional to the product of torque and speed, it follows that, if the electrical and mechanical design permits, the B.H.P. which can be developed by a given carcase varies with the speed. This variation is illustrated by the following figures, taken from a maker's catalogue, which relate to a stock size of carcase for a 230V D.C. shunt motor:—

Output in B.H.P.	Speed in r.p.m.	Approximate percentage efficiency at full load.	Price.
30	1,360	90	P.
22	900	88	P.
17	660	87	P.
15	575	86	P.
12·5	515	85	0·97P.
10	420	84	0·97P.

As an example of the comparative weights, &c., of D.C. shunt motors of the same H.P. but of different speeds, it may be stated that a 30 H.P. motor built to run at 360 r.p.m. is approximately double the weight, 2¼ times the bulk, and twice the cost of one built to run at 1,360 r.p.m., and its full-load efficiency is about 5 per cent. less

93. *Rating of motor startors.*

Face-plate rheostatic startors for D.C. motors, which are not ordinarily required to be started more than twice an hour, are dealt with in B.S.S. No. 246, from which the following information has been extracted :—

i. *Types of enclosure.*—The following types are recognized :—
   - (*a*) *Open* (suitable for use by *skilled attendants only*).
   - (*b*) *Enclosed ventilated.*
   - (*c*) *Totally enclosed.*
   - (*d*) *Drip proof* (with ventilated openings so protected as to exclude dirt or moisture).
   - (*e*) *Weather proof* (totally enclosed with watertight joints).
   - (*f*) *Flame proof.*

ii. *Standard sizes.*—The following sizes are given as standards :—

   ¼, ½, 1, 2, 3, 4, 5, 7½, 10, 12½, 15, 20, 25, 30, 35, 40, 45, and 50 Horse-Power.

iii. *Classes of rating.*—Two standard classes of rating are recognized :—
   - (*a*) Ordinary duty.
   - (*b*) Heavy duty.
   - (*a*) An ordinary duty startor is suitable when the working conditions are such that the time required to start the motor from rest to full speed is not longer than the starting period specified (*see* sub-para. v (*a*)) while the limitation of current peaks specified (*see* sub-para. (vi)) is complied with.
   - (*b*) A heavy duty startor is suitable for use on services having more than the usual amount of flywheel effect, such as for punch presses, circular saws, and other tools having heavy flywheels. It is not, however, suitable for more severe services, such as motors driving machines requiring more than 60 seconds to start.

iv. *Thermal capacity of startors for ordinary or heavy duty.*—
A standard startor having ventilated resistances shall be capable of starting up the motor from rest, under the conditions specified in sub-paras. (v) and (vi), five times in succession without injury, with an interval between successive starts of fifteen times the starting period.

A standard startor having totally enclosed resistances shall be capable of starting up the motor from rest, under the conditions specified in sub-paras. (v) and (vi), three times in succession without injury, with an interval between successive starts of fifteen times the starting period.

v. *Starting period for test.*—The starting period of the motor from rest to full speed shall be :—

(*a*) *For ordinary duty startors.*—Five seconds plus half a second for each 1 H.P. of the motor rating.

(*b*) *For heavy duty startors.*—60 seconds.

vi. *Normal start for ordinary duty and heavy duty startors.*—
This shall be as follows :—

(*a*) The current on the first contact shall not exceed the following values :—

For startors up to and including 7½ H.P., 1½ times full-load current.

For startors above 7½ H.P., full-load current.

(*b*) The maximum value of the current peaks, when switching from contact to contact, shall not exceed 150 per cent. of the rated full-load current for D.C. motors.

It is not considered practicable to specify limits for current peaks with A.C. motors.

vii. *Construction.*—The following points are specified :—

(*a*) No combustible material to be used.

(*b*) All joints in electrical conductors to be mechanically connected, whether soldered or not.

(*c*) Renewable contacts to be provided above 12½ H.P. at 110V, and above 20 H.P. at 220V to 600V.

(*d*) Direction of rotation of handle when starting up to be clockwise.

(*e*) A spring, or other means, to be provided on D.C. startors to prevent any part of the starting resistance being left in circuit.

(*f*) A separate switch to be provided for breaking the main circuit and should be used on all ordinary occasions, the startor returning to the "off" position when released automatically.

(*g*) A no-volt release to be provided on D.C. startors.

(*h*) Field circuit must not be disconnected from mains without a discharge path.

(*i*) Provision must be made to secure conduit to startor and to enclose completely the cable entering the startor.

* * * * * *

A list of British Standard Specifications for other Motor Startors is given at the end of the chapter.

94. *Suitability of motors for use on other than the rated voltage and frequency.*

1. **Standard voltages.**—B.S.S. No. **77** specifies the following standard voltages for new installations :—

Type of current.	Consumer's voltage (declared).	Station voltage.
	volts	volts
D.C.	230, 460	250, 500
A.C.	230, 400	250, 440

All other voltages may now be considered as obsolescent in this country, but it will be many years before they are obsolete, and, moreover, they may often be met with abroad. It would, therefore, be a great convenience from a military point of view if motors could be stocked suitable for several different voltages.

2. **D.C. motors.**—If it is attempted to run a D.C. motor at full load on voltages much below the rated value, overheating of armature and series coils and commutator will result, and there may be excessive sparking and instability in running. In the case of shunt machines, the speed may not differ much from the rated value.

On the other hand, if the voltage is much too high the speed will generally be excessive, the shunt field coils will overheat and there will be excessive sparking at the commutator, probably resulting in a "flash-over."

For commercial purposes, it is not usual to employ D.C. motors on systems where there is more than 5 per cent. difference between the declared supply voltage and the rated machine voltage. For military purposes, a difference of

10 per cent. can usually be worked to with satisfactory results in ordinary workshop practice and in other cases where machines do not run continuously at full load.

If the difference of voltage is greater than 10 per cent., it will invariably be necessary to rewind both armature and field. It is quite impracticable to run a 110V D.C. motor on a 220V system.

In the case of a shunt machine with the field coils normally connected all in series, a little consideration will show that if the field coils are re-arranged in two halves connected in parallel, such a machine will develop *half* its rated H.P. at *half* its rated speed if supplied at *half* its rated voltage.

3. **A.C. 3-phase induction motors.**—In this type of machine, since energy is transmitted to the rotor by transformer action, the stator winding can be subdivided in the same way as the windings of a transformer, as explained in Sec. **21**, para. **11**.

If the stator winding is insulated for 2V volts, and each phase winding is divided into two equal parts, machines can be stocked suitable for use on four distinct voltages, viz., $2V, \frac{2V}{\sqrt{3}}, V,$ and $\frac{V}{\sqrt{3}}$, by making use of star and delta series and parallel connections.

4. **Single-phase induction motors and repulsion motors.**—These can be arranged for use on two different supply voltages, V and 2V, by subdividing the stator winding into two equal parts, which are connected in series for 2V and in parallel for V volts.

On a given frequency, the speed of induction motors is practically independent of the supply voltage for small variations of the latter, and such machines work satisfactorily without modification over much larger ranges than D.C. machines.

5. **Effect of change of frequency.**—The synchronous speed of an induction motor is directly proportional to the supply frequency. Consequently, if a machine designed for 50 cycles is run on a 25-cycle supply, it will run at half its rated speed and will only develop half its rated H.P. Moreover, there will be such a large increase in the magnetizing current that serious overheating will occur even when running light. Conversely, if a 25-cycle motor were connected to a 50-cycle supply its speed should be theoretically double the rated value, but the machine would probably be wrecked before such an excessive speed could be attained.

6. **Change of frequency and voltage simultaneously.**—It is usual for makers to guarantee the performance of induction motors if the change of frequency + change of

voltage does not exceed ± 10 per cent. It is not often that the frequency varies from the declared value by more than the statutory 2½ per cent.

95. *Purchase of motors and control apparatus.*

1. **Motors.**—Inquiries based on British Standard Specifications will enable a purchaser to compare, on a common basis, tenders received from various manufacturers, and, as a general rule, when sending an inquiry or order for electrical machinery it will only be necessary to give the information specified below, stating at the same time that the machinery is to comply with the latest editions of the appropriate British and Government Department Specifications.

i. *General information required for all motors.*
  - (*a*) Class of rating (continuous or short-time).
  - (*b*) Type of machine (open, enclosed, &c.).
  - (*c*) Maximum air temperature.
  - (*d*) Altitude (if it exceeds 3,300 feet).
  - (*e*) If a machine is required to operate between various limits of voltage, current, frequency, or speed, the corresponding value of the voltage, current, frequency, and speed respectively.
  - (*f*) System of earthing, if any, to be adopted.
  - (*g*) Particulars of tests required, and where they are to be carried out.
  - (*h*) Particulars as to whether voltage-limiting devices will be employed.

ii. *Additional information for D.C. motors.*
  - (*a*) Mechanical output at the shaft, in H.P.
  - (*b*) Supply voltage.
  - (*c*) Approximate speed at rated output.
  - (*d*) Method of excitation (whether shunt, series, or compound).

iii. *Additional information for induction motors.*
  - (*a*) Frequency.
  - (*b*) Number of phases.
  - (*c*) Mechanical output at the shaft, in H.P.
  - (*d*) Supply voltage.
  - (*e*) Approximate speed at rated output.
  - (*f*) Whether squirrel-cage or wound rotor.
  - (*g*) Method of starting to be employed.
  - (*h*) Starting torque required in terms of the rated full-load torque and the corresponding starting current which can be taken from the supply with the starting accessories connected.
  - (*i*) Whether brush-lifting and short-circuiting gear is required.

When accepting quotations, the efficiency and power factor (in the case of A.C. machines) should be taken into consideration as well as the price.

2. Control apparatus.—Startors and regulators are generally supplied separately, and it should be clear that listed prices and quotations for motors do not include control apparatus unless particularly specified.

Face-plate startors for D.C. motors should comply with British Standard Specification No. 246. For other types of startor, see list at end of chapter.

The information required is as follows :—

i. *D.C. startors.*
  (*a*) Rated B.H.P. of motor.
  (*b*) Supply voltage.
  (*c*) Field winding—whether series, shunt, or compound.
  (*d*) Shunt-field current.
  (*e*) Required starting torque in terms of normal full-load torque.
  (*f*) Whether the rheostat is required simply for starting purposes or whether continuous speed regulation is desired. If the latter, the percentage of regulation and the B.H.P. at lowest speed to be stated.
  (*g*) Automatic features required.
  (*h*) Type (open or enclosed).

ii. *Shunt-field rheostats for speed regulation.*
  (*a*) Rated B.H.P. of motor.
  (*b*) Supply voltage.
  (*c*) Field winding (shunt or compound).
  (*d*) The resistance of shunt-field coil (cold).
  (*e*) The approximate resistance required in series with the shunt-field coil to produce the required variations in speed.
  (*f*) Number of steps of resistance required.

iii. *Rotor rheostats for 3-phase slip-ring induction motors.*
  (*a*) Rated B.H.P. of motor.
  (*b*) Voltage and frequency of supply.
  (*c*) Voltage between slip-rings with rotor at rest.
  (*d*) Rotor connections, whether star or delta.
  (*e*) Full-load current of rotor.
  (*f*) Required starting torque in terms of full-load torque.
  (*g*) Whether rheostat is required simply for starting purposes or if continuous speed regulation is desired. If the latter, the percentage of

regulation and the B.H.P. at lowest speed to be stated.
- (*h*) Automatic features required.
- (*i*) Type (open or enclosed).

iv. *Star-delta or auto-transformer startors for 3-phase squirrel-cage motors.*—These are invariably supplied totally enclosed.
- (*a*) Rated B.H.P. of motor.
- (*b*) Voltage and frequency of supply.
- (*c*) Automatic features.
- (*d*) Whether wall type or floor type required.
- (*e*) Whether air- or oil-break required.

96. *Regulations to be observed in motor installations.*

1. The **principal authorities** who make rules and regulations are :—

i. The Electricity Commissioners.
ii. The Home Office.
iii. The Institution of Electrical Engineers.

The Electricity Commissioners' regulations deal with questions of general supply, and protect both the interests of consumers and suppliers. They do not apply to **L.V.**, *i.e.*, voltages below **250V**.

The Home Office regulations for factories and workshops are principally concerned with the safety of attendants and workers, and they apply to D.C. installations above **250V** and to A.C. above **125V**.

The I.E.E. Regulations for the Electrical Equipment of Buildings are framed to ensure the safety of the installations themselves, particularly from a fire-risk point of view. These Regulations apply to L.V. and M.V., *i.e.*, all voltages up to **650V**. Practically all the Fire Insurance Companies now accept the Wiring Regulations of the I.E.E.

Although the War Department are under no legal obligation, they are morally compelled to comply with these regulations where circumstances permit. This means that under peace-time conditions they must always be rigidly complied with.

For general guidance, the principal rules and regulations particularly affecting motor installations will now be given.

2. **Electricity Commissioners' regulations.**

A—Regulations for securing the Safety of the Public.

General.

1. The voltage of a supply delivered to any consumer shall not exceed the limit of low voltage (*see* Sec. 18, para. 2), except for special purposes, for which a medium voltage (*see* Sec. 18, para. 2) supply may

be given on the consumer undertaking to comply with the following conditions :—

(*a*) Where the supply is for power purposes—

1. The frame of every electric motor shall be efficiently connected with earth.
2. The consumer's wires forming the connections to motors, or otherwise in connection with the supply, shall be, as far as practicable, completely enclosed in strong metal casing efficiently connected with earth, or they shall be fixed in such a manner that there shall be no danger of any shock.
3. The supply to every motor shall be controlled by means of an efficient cut-off switch, placed in such a position as to be easily handled by the person in charge of the motor, and connected so that by its means all voltage can be cut off from the motor itself, and from any regulating switch, resistance, or other device in connection therewith.
4. Switches, efficient fuses, or other automatic circuit-breakers shall be provided, so as to protect the circuits from excess of current, and all switches and cut-outs shall be so enclosed and protected that there shall be no danger of any shock being obtained in the ordinary handling thereof, or of any fire being caused by their normal or abnormal action.
5. A notice shall be fixed in a conspicuous position at every motor and switch-board in connection with the supply forbidding unauthorized persons to touch the motors or apparatus.

3. Home Office regulations for factories and workshops.

1. All apparatus and conductors shall be sufficient in size and power for the work they are called upon to do, and so constructed, installed, protected, worked, and maintained as to prevent danger so far as is reasonably practicable.

* * * * *

11. Every motor, convertor, and transformer shall be protected by efficient means suitably placed, and so connected that all voltages may thereby be cut off from the motor, convertor, or transformer as the case may be, and from all apparatus in connection therewith ; provided, however, that, where one point of the system is connected to earth, there shall be no obligation to disconnect on that side of the system which is connected to earth.

This regulation implies a double-pole or three-pole main switch in an easily accessible position.

12. Every electrical motor shall be controlled by an efficient switch or switches for starting and stopping, so placed as to be easily worked by the person in charge of the motor. In every place in which machines are being driven by any electric motor there shall be means at hand for switching off the motor or stopping the machines if necessary to prevent danger.

* * * * *

21. Where necessary to prevent danger, adequate precautions shall be taken, either by earthing or by other suitable means, to prevent any metal other than the conductor from becoming electrically charged.

This regulation implies the earthing of the metal framework of motors, startors, switch boxes, &c.

4. The Institution of Electrical Engineers' Regulations for Electrical Equipment of Buildings.

Earthing (for full particulars *see* Regulation 96).—For all voltages, adequate precautions must be taken, either by earthing or other suitable means, to prevent any metal other than the conductor (such as the cases of switches, fuses, startors, and the frames of dynamos and motors) from becoming electrically charged.

Motors.

117. *Types.*—

A. Motors may be of any of the types enumerated in British Standard Specification No. 168, or of the immersible type, and all motors rated at more than one brake horse-power shall conform in all respects to that Specification.

B. The frame of every motor shall be provided with a suitable terminal to which the earthing lead may be connected.

118. *Position.*—

A. Motors shall, wherever possible, be placed in well-ventilated spaces in which inflammable gases cannot accumulate. Where these conditions cannot be complied with, the motors shall be of the flame-proof or pipe-ventilated type with inlet and outlet connected to the outer air.

B. Motors fixed in situations in which the surrounding air exceeds the limit of temperature permitted for the cooling air in the appropriate British Standard Specification shall be of special construction, or, alternatively, of the pipe-ventilated, forced-draught or induced-draught type, connecting by ventilating ducts to a source of cool air supply.

C. Motors shall, as far as possible, be placed in positions in which they are not exposed to risk of mechanical injury or to damage from water, steam, or oil. Motors necessarily exposed to such conditions shall have suitable types of enclosing frames selected from the standard "types of enclosure" specified in British Standard Specification No. 168.

D. Pipe-ventilated, forced-draught, and induced-draught motors shall be supplied with air as cool as possible, and the air intakes shall be guarded against the admission of dirt and/or moisture.

E. No unprotected woodwork or other combustible material shall be within a distance of 12 inches (30 cm.) measured horizontally from, or within 4 feet (120 cm.) measured vertically above, any motor, unless such motor be of the totally enclosed, flame-proof or pipe-ventilated type with inlet and outlet connected to the outer air. A metal plate or tray extending 12 inches (30 cm.) beyond the base of the machine shall be placed under every open-type machine which is mounted on a floor consisting of wood or other combustible material.

119. *Control of Motors.*—

A. Every motor shall be protected by efficient means, suitably placed and so connected that the motor and all apparatus in connection therewith may be isolated from the supply; provided, however, that when one point of the system of generation or supply is connected to earth, it shall not be necessary to disconnect on that side of the system which is connected to earth.

> NOTE.—In the case of motors not exceeding one brake horse-power a plug and socket will be considered to be an efficient method of isolation from the supply.

B. Every motor shall be provided with an efficient switch or switches for starting and stopping, so placed as to be easily operated by the person controlling the motor; and every motor having a rating exceeding one-half horse-power shall in addition be provided with :—

(*a*) Means for automatically opening the circuit if the supply voltage falls sufficiently to cause the motor to stop.

(*b*) In the case of direct-current motors, a startor or switch for limiting the current taken when starting and accelerating.

(*c*) In the case of alternating-current motors, such startor or switch for limiting the current taken, when starting and accelerating, to the value (if any) required by the supply undertaking.

C. In every place in which a machine is being driven by a motor there shall be means at hand for either switching off the motor or stopping the machine if necessary to prevent danger.

Testing.

See extract from I.E.E. Wiring Regulations in Sec. **74**, para. **3**.

97. *Current required by motors.*

The current taken by a motor under load can be found as follows :—

i. *D.C.*, $\mathrm{I} = \dfrac{\mathrm{B.H.P.} \times 746}{\mathrm{V} \times \eta}$ amperes.

ii. *A.C. single-phase,* $\mathrm{I} = \dfrac{\mathrm{B.H.P.} \times 746}{\mathrm{V} \times \eta \times \cos\phi}$ amperes.

iii. *A.C. 3-phase,* $\mathrm{I} = \dfrac{\mathrm{B.H.P.} \times 746}{\sqrt{3} \times \mathrm{V} \times \eta \times \cos\phi}$ amperes per phase.

η = efficiency.

In the absence of precise information, full load efficiencies may be taken from the curves given on Pl. **120**, and, for A.C. machines, a power factor of 0·8 may be assumed.

Table **Y** gives full-load current values which are close enough for practical purposes when estimating capacity of switches, &c., and the size of mains required. The figures refer to 230V machines. To obtain the current required at other voltages, it is sufficiently correct to assume that the current is inversely proportional to the rated voltage.

TABLE Y.—*Approximate full-load currents of motors.*

Rated B.H.P.	Full-load current.		
	D.C., amperes.	A.C. single-phase, amperes.	A.C. 3-phase, amperes per phase.
1	5	7	3·5
3	13	18	9·5
5	21	28	15
7½	31	41	22
10	40	53	29
12½	50	—	36
15	60	—	43
20	78	—	56
30	114	—	83
40	151	—	109
50	188	—	134

It may be found useful to note that the current required per B.H.P. at 230V is approximately as follows :—

3-phase A.C. (per phase)	3A per B.H.P.
D.C.	4A ,, ,,
Single-phase A.C.	5A ,, ,,

98. *Temperature and dielectric tests.*

To comply with the British Standard Specification, machines should pass the following tests :—

i. **Temperature tests.**—The temperatures of the various component parts of a machine should not exceed those given in Sec. **91**, para. 2, after a full-load run, long enough to establish that the maximum working temperature has been reached. The normal test period for machines of about 20 H.P. may be taken as 6 hours, but small machines of a few H.P. reach their maximum temperatures in a much shorter time and very large machines naturally take a much longer time. It is advisable to note temperatures at intervals during a run and plot temperature-time curves. The run may be stopped when the curve becomes approximately horizontal.

Measurement of temperatures by thermometer is considered sufficiently satisfactory.

ii. **Dielectric tests.**—The following tests should be made at the conclusion of the temperature tests while the windings are hot :—

(*a*) *Minimum insulation resistance.*—The insulation resistance in megohms when the high voltage test is applied should not be less than

$$\frac{\text{Rated voltage}}{1{,}000 + \text{rated output in kVA or B.H.P.}}$$

The insulation resistance should be measured with a voltage of about 500V D.C., applied for a sufficient time for the reading of the indicator to become practically steady.

(*b*) *High voltage test.*—This should be applied only to a new and completed machine in normal working condition, with all its parts in place. It is generally advisable that it should not be applied when the insulation resistance is less than that specified in (*a*) above.

The voltage should be applied gradually and maintained for one minute between the windings and the frame of the machine, with the core connected to the frame and to the windings not under test.

The test voltage should be based on the rated voltage, or the highest R.M.S. voltage reached between any part of the winding and the frame, whichever is the greater, and should be as follows :—

Machines of sizes 1 *B.H.P. and above, but below* 3 *B.H.P.* 1,000V + twice the rated voltage.

Machines of sizes 3 *B.H.P. and above.* 1,000V + twice the rated voltage (with a minimum of 2,000V).

Secondary (rotor) windings of induction motors not permanently short-circuited. For non-reversing motors, 1,000V + twice the maximum voltage that could be induced between the slip-rings. For reversing motors, 1,000V + four times the voltage between the slip-rings at standstill on open circuit, with the full primary voltage applied to the stator windings.

iii. **Motor startor dielectric tests.**

(*a*) *Minimum insulation resistance.*—Measured with 500V D.C. as in sub-para. ii (*a*), this should not be less than one megohm.

(*b*) *High voltage test.*—As given in sub-para. ii (*b*) for motors. Value of Test Voltage = 1,000V + twice the rated voltage of startor — (minimum value 2,000V).

For further details, reference must be made to the Standard Specifications.

99. *Comparison between D.C. motors and 3-phase A.C. induction motors.*

Table **Z** gives, for comparison purposes, the most important particulars for constant speed machines of the same B.H.P. and speed.

TABLE **Z**.—*Comparison between D.C. and 3-phase A.C. induction motors.*

Type of motor.	Cost.	Weight.	Full-load efficiency.	Full-load power factor.	Remarks.
D.C.	P	W	E	—	—
3-phase A.C. wound rotor from	0·7P	0·7W	1·05E	0·75	According to size.
to	0·8P	0·8W	0·95E	0·90	
3-phase A.C. squirrel-cage rotor from	0·4P	0·7W	1·05E	0·75	According to size.
to	0·5P	0·8W	0·95E	0·90	

NOTE.—The figures for cost and weight are for machines complete with slide rails but *without* startors.

This table shows that the A.C. machine is lighter and cheaper than the D.C., and that their efficiencies are approximately equal.

A startor is absolutely necessary with a D.C. motor but not with an A.C. motor. The former may attain a dangerous speed under certain conditions but the latter cannot race.

The A.C. machine is simpler to operate and maintain, particularly with a squirrel-cage rotor.

The A.C. machine is less affected by variations in the supply voltage. Moreover, by simple subdivision and interconnection of the stator winding, the machine can develop its maximum output at rated speed on several distinct supply voltages (*see* Sec. **94**, para. 3). The D.C. motor can operate on one voltage only.

The wiring costs for the A.C. machine are approximately the same as for the D.C. machine, notwithstanding the low P.F. of the former.

The only important advantage possessed by the D.C. machine is its adaptability for economical speed control. However, it must not be overlooked that the relative prices given in Table **Y** are for so-called constant speed machines, of which the D.C. type will permit of only 10 to 15 per cent.

variation by field regulation. If a greater percentage of speed regulation is desired, a larger and more expensive D.C. machine is necessary.

The low P.F. of the induction motor has not hitherto caused much inconvenience to the consumer, but in the future it will probably mean rather larger charges for A.C. power than for D.C., as explained in Sec. **34**, para. 9.

100. *Selection of motors.*

1. The characteristics of the common types of motors having been explained, it is now possible to select the size and type of motor required for any particular service, if the following information is available :—

- i. Characteristics of the load and its maximum and average values.
- ii. Supply voltage and frequency.
- iii. Nature of the supply (D.C., or single-phase or 3-phase A.C.).
- iv. Requirements of the supply authorities (as to type, starting current, power factor, &c.).

The correct B.H.P. to install is best found by trial. In the case of belt-driven machines, it is often possible to carry out the necessary tests at stations where other motors and testing instruments are available. However, reliable figures for various machines are given in the Textbook of Mechanical Engineering, or, alternatively, can be obtained from the manufacturers of the machines. Theoretical calculations based on depth of cut and cutting speed are practically valueless in deciding upon the size of motor required. In some cases (*e.g.*, a 4-cutter universal wood-working machine), the machine itself takes from 50 to 70 per cent. of the full-load power. It must also be borne in mind that an allowance of from 5 to 10 per cent. should be made for belt losses, owing to the comparatively small pulleys of the motors. Such losses will, of course, be included in the figures obtained by tests, but they are not included in the figures given in the Textbook of Mechanical Engineering, for H.P. of machines.

It frequently happens that the H.P. required depends upon the skill of the operator. This is particularly the case with circular saws. Nevertheless, the want of skill of operators can only be considered a valid reason for installing extra large machines when skilled men are scarce. Too large a motor not only means increased installation costs, but also increased running costs, owing to reduced efficiency and power factor. In the case of pumps, fans, compressors, and the like, it is good practice to put in motors 25 per cent. larger than calculations show to be necessary. In the case of machine tools, which repeat fairly definite and regular " duty cycles " of short duration, the average load should be the criterion. In deciding the type to install, every endeavour should be made to use :—

Shunt motors on D.C.

Squirrel-cage induction motors on A.C.

There are few military requirements which cannot be satisfied by these types of machine.

D.C. and single-phase A.C. series motors are better for cranes and for traction purposes (especially from the power supplier's point of view). D.C. compound motors are useful for lifts and for machines in which the load fluctuates violently, as in punching and shearing machines; also for wood-working machinery where the load is a very fluctuating one, due to knots, uneven sawing, nipping of timber, and the difference between wet and dry timber.

It is, however, more for the power supplier's interests that compound motors are recommended. For machines up to (say) 15 B.H.P. the ordinary shunt motor is quite satisfactory.

3-phase slip-ring induction motors are used for cranes, and they may be necessary in cases where considerable starting torque is demanded, although the simple squirrel-cage type can often be used in such cases by starting up on a loose pulley or a centrifugal clutch.

The type of startor to use with a squirrel-cage motor will depend upon the starting torque required and the limitation imposed by the supply company.

The auto-transformer startor is the best, but as it is somewhat expensive it should only be used when the requirements cannot be met by the star-delta type. The high starting torque squirrel-cage motor should not be lost sight of in this connection.

Punching and shearing machines, centrifugal machines such as hydro-extractors and four cutter universal woodworking machines are examples of machines requiring a high starting torque. The four cutter is a machine which takes a minute or so to get under way with a starting torque equal to the normal full load value, and therefore if D.C. or 3-phase slip-ring machines are installed the startors should be rated for heavy duty. The possibility of using *short-time* rated machines should always be considered as they are much lighter and cheaper than continuous rated machines. " Short-time " rated machines are suitable for cranes and circular saws and possibly other types of workshop machinery. The choice cannot be settled by calculation, but it is a matter for judgment based on experience.

Enclosed motors will be necessary if the machines have to work in an atmosphere charged with dust, *e.g.*, in saw mills and flour mills. In this connection, it should be noted that boxing an open type machine in a wooden or iron cover converts it into an enclosed machine and, therefore, reduces its rated output.

Automatic control gear is desirable in commercial workshops where every machine is worked to the utmost extent, since it enables semi-skilled operators to be employed and ensures the maximum possible output from each machine. This is not of importance in military workshops, as there is seldom sufficent personnel to operate all the machines at the same time, and ordinary hand control is sufficient.

2. *Group* versus *individual driving in factories and workshops.*—In designing the lay-out for electrically driven machinery in a workshop or factory, a balance has to be struck between employing a separate motor for each machine, however small, and one large motor which is capable of driving all the machines together.

The most economical arrangement depends entirely upon the nature of the load.

A good deal has been published in favour of individual motors for each machine, and it is argued that instead of investing money in shafting and belting it can be more economically invested in the purchase of electric motors for individual drive, which is indisputably the most desirable arrangement from an operating point of view.

Moreover, the power consumption with individual driving is usually much less than with group driving, but the cost of power in a workshop is a small proportion only of the total running costs, and it may take many years to make up for the heavy installation costs of the wholly individual drive.

A generally accepted rule is :—Group convenient machines, allowing for diversity factor, to motors of 5 H.P. and give separate motors to machines taking more than 5 H.P. It must be understood, however, that this is a rough rule only.

Group driving may be cheaper in first cost and is particularly applicable where all the machines are not in constant use. This is frequently the case in military workshops. If the machines are judiciously grouped, considerable economy in motor capacity will result. For instance, if there are three or four machines, each liable to sudden overloads, which might necessitate a much larger individual motor than the normal load would require, it might be possible to drive them collectively by one comparatively small motor.

Individual drive is better for portable machines and for machines necessitating considerable expenditure for shafting (and incidentally large friction losses).

It is sometimes advocated in favour of group driving that the motor efficiency of one or two large motors is better than that of a large number of smaller motors. This is true (*see* Pl. **120**), but consideration from this standpoint alone is not sound, because the inefficiency of the extra shafting required more than counterbalances the advantage due to the higher efficiency of the larger motors.

It is not always realized what an enormous loss of power may take place in shafting. From the results of a large number of observations made in engine-driven workshops, it has been found that the mechanical efficiency of the shafting may range from 25 per cent. to 70 per cent. at full load.

The average efficiency is probably nearer the former figure than the latter, since full load is not often met with and the shafting loss is practically the same when all the machines are idle as when they are fully loaded.

In cases where old shops are completely equipped with line shaft drive it may not pay to scrap all the overhead work at once, and the group system with one or two large motors is no doubt the most economical arrangement, all things considered. Exception should be made in the case of isolated machines. For a small machine in a distant part of the shop, it should not be necessary to drive a long shaft, which consumes about six times as much power in friction as is actually needed at the machine.

In conclusion, it must be pointed out that consideration of the subject from a financial point of view is not always possible for military purposes, and the wholly individual drive may be essential on grounds of expediency. In Field Service workshops, the provision of each machine with its own built-in motor not only considerably simplifies transport but entirely abolishes shafting, &c., with the result that the machines can be put to work immediately they are unpacked, as no time and labour are required for erection of shafting, as is the case with the belt-driven system.

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168. Electrical Performance of Industrial Motors and Generators.
170. Fractional Horse Power Motors.
246. Face-Plate Startors.
247. Face-Plate Rotor Startors.
280. Field Rheostats for Generators, Motors, &c.

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No. 15. Alternating Current Motors, 1 to 100 B.H.P.

CHAPTER XIV.

PRACTICAL NOTES ON ELECTRICAL MACHINERY.

These notes apply more particularly to ordinary D.C. machines of moderate size, and they may require modification or amplification for machines of large size, say, above 50 H.P. or for machines of special design.

101. *Installation, inspection and testing.*

1. Installation.—For best results, electrical machinery must be installed in a clean, dry, well-ventilated place, easily accessible and in plain sight.

Machines must not be placed under steam or water pipes, or otherwise exposed to dripping moisture. They must be kept as free as possible from oil, grease, and dirt, unless special provision is made in the construction to prevent injury from these sources.

Cleanliness is very important.—Oil, water, and dirt have a very deleterious effect on the insulation. However carefully the windings may be impregnated and varnished, they cannot stand up to being soaked with oil indefinitely. Freedom from acid fumes is essential, and the machine must not be exposed to excessively high temperature surroundings, *i.e.*, where the ultimate temperature of the windings at full load will exceed 90° C. (This temperature limit does not apply to machines insulated with mica.)

In certain cases where space is restricted it may be practicable to fix motors on to walls or pillars, but it must be remembered that vibration is one of the greatest enemies of all running machinery, and nearly always leads to undue wear and tear. Rigidity is essential, and hence a site should be selected where a proper concrete foundation can be put in. Another argument in favour of placing all machines on the floor is that of accessibility.

In whatever situation a machine may be placed, reserve sufficient space for the attendant to go completely round it for purposes of oiling bearings, adjusting brushes, &c.

Whether inside or outside a building, protection from damp and dust is essential, and when selecting the type to install (*see* Sec. **91**), due regard must be paid to the conditions under which the machine will have to work. The various regulations should be carefully studied concerning the safety precautions to be taken to minimize danger from fire and from shock or other injury to personnel. PREVENTION IS BETTER THAN CURE.

By the requirements of the Factory Acts, all belts and gearing must be protected against accidental contact with workmen, either by casing in completely or by fencing round in such manner that no one passing can get his clothes caught up by any running parts.

The electrical requirements are laid down in the Home Office and the I.E.E. Regulations.

Notices clearly indicating the danger of touching electrical machinery and apparatus, as a warning to unauthorized persons, should be placed in conspicuous positions.

2. Inspection and Testing.—New machines will usually be inspected and tested at the makers' works by the C.I.R.E.S., in which case serious electrical or mechanical defects are not likely to be found unless they occur in transit.

On receipt of a new or second-hand machine, it should first be examined to see that no parts are missing, and that the electrical connections are complete and correct. It should then be overhauled and cleaned, and, if necessary, dried out. The terminals are normally protected by an iron box, to cover all exposed live metal parts.

Assuming that the armature, commutator and brushes are in good order (faults in these parts will be dealt with in detail later), and that the lubricating arrangements are working correctly, the following points should be noted :—

i. With the brushes raised, see if the armature rotates with perfect freedom in the bearings. There should be no appreciable slackness, no tight places, nor any tendency to stop always at one point when coming to rest, which would indicate want of balance. Slackness is invariably due to worn or slack bearings, and tightness may be due to the bearings or to the armature fouling some of the pole pieces.

   Want of balance is generally due to a displaced balance weight, or possibly to some of the end windings having become displaced by centrifugal force when the machine at some time was run at an excessive speed.

ii. When the drive permits, there should always be a decided amount of end play in the bearings, from $\frac{1}{16}$ in. to $\frac{1}{8}$ in. in the case of plain bush bearings, or if ball bearings are fitted, only one ball race should be fixed laterally, and the other should be free to slide in its housing slightly to allow for expansion of the shaft with rise of temperature.

iii. The end play should be again tested later, when the machine is at work and the fields magnetized, since, unless the armature is well centred axially as regards the pole pieces, it will tend to draw itself strongly toward their middle region and cause one shoulder of the shaft to come hard up against the bearing bush, and so cause overheating.

It may be necessary to file a little off the end of the brass, or to shift the pedestal by drawfiling the holes, or to do both until the brass and collar are clear of each other. Running the machine light as a motor is the best method of verifying this, and the armature should "float" in its bearings with neither shoulder at the shaft ends touching the bearing brasses. If pushed out of this position by pressure at the end of the shaft while running, it should quickly return to its running position.

iv. Test the armature to see if it is exactly concentric with the bore of the pole pieces. If not, the bearings should be suspected first, but it may be necessary in rare cases to insert a thin piece of sheet iron between the magnet limbs and the yoke, or to reduce the limbs a little so as to bring them nearer to or further from the armature, as required.

If the air-gap is uneven, the machine will tend to spark at the brushes, and there will be a larger pull from the field magnets on that side of the armature having the smaller clearance, tending to increase wear of bearings.

v. If the machine is found to be in good order when run light for short periods, it should then be run for some hours at full load to see that there is no sparking or overheating.

3. **Maintenance.**—Electrical machinery, as a rule, requires such little attention that it is left for long periods with none at all—beyond perhaps a superficial "wipe down" of the exterior of the frame occasionally. But regular and systematic inspection is essential.

KEEP THE MOTOR OR GENERATOR CLEAN.

A small portable electric blower is a useful appliance, and is almost indispensable when the number of machines is large.

The insulation must be kept clean and dry. Oil and dirt in the insulation are as much out of place as grit or sand in a cylinder or bearing. In a direct connected generating set oil may splash from the engine, or work along the shaft to the insulation, and eventually cause a burn out.

Bearings may become so much worn that the armature gets badly out of the pole centre or a pulley set-screw may work loose, or the tension of the belt may have been wrongly adjusted and excessive load thereby put on the bearings. If these faults are put right in the incipient stage, a lot of inconvenience and expense will be avoided.

A machine should receive attention daily if possible, or at any rate once a week—whether it appears to want it or not. This should include careful examination of the bearings, commutator, and brushes, gearing or pulley and belt, and the armature and field for loose or broken wires. If the field of a shunt motor is disconnected, the machine may race and destroy the armature winding. This seldom happens except through carelessness or neglect.

4. **Spare Gear.**—It is advisable to keep a stock of spare gear and repair materials. The nature and quantity will depend upon the type and size of the installation, but the following items are among those which it may be considered desirable to stock :—

Spare brushes (complete set), brush-holder springs, insulating washers for brush spindles, mica sheet and insulating tape for repairs to coils, spare contacts for shunt regulators and starting switches, carbon tips and flexible connections for circuit-breakers, and any other small parts which are likely to wear out or perish.

5. **Records.**—The first essential when a machine is installed is to enter detailed particulars on an A.F., G.927 T., and also on an index card A.F. G.924 (D.E. J or K) for transmission to War Office, who will then allot a W.D. number. The G.927 T. then becomes the *medical history sheet*, and all important repairs and tests should be entered thereon. The attendant should be required to keep a log book giving a complete record of all inspections, adjustments and repairs carried out. (*See* R.E.S., Pt. II—1928, para. 23.)

102. *Brushes.*

There is a very large variety of carbon brushes to choose from, ranging from the comparatively soft graphite to the highly refractory electro-graphitic brush. Table **ZA** will serve as a rough guide to the more important properties and uses of carbon brushes, but there is a wide range with varying degrees of hardness, &c., in each type.

1. **Nomenclature.**—Fig. 84 explains the terms length, width, thickness, chamfer, top, contact surface, entering edge and leaving edge. The dimensions should always be given in the order length, width, thickness.

2. **Ordering New Brushes.**—When ordering new sets of brushes it is better to get them from the machine makers ; otherwise the following particulars should be given (unless the exact type and make of brush are known) :—

Total output of machine, voltage, speed, diameter of commutator, number of segments, number of sets of brushes, and number of brushes per set. Also a sample brush, if available ; if not, a dimensioned sketch, including the method of fixing the tail.

Modern machines will probably have British standard sizes of brush (*see* B.S.S. 96).

3. Running Position of Brushes.—On machines fitted with commutating poles the running position will be at or very near the geometrical neutral position; sometimes a shade in front if the machine is a motor, so as to prevent it from gathering speed as the load increases, and sometimes a shade behind if a generator, to give a slight compounding effect. A very small brush movement on a machine fitted with commutating poles produces a marked effect.

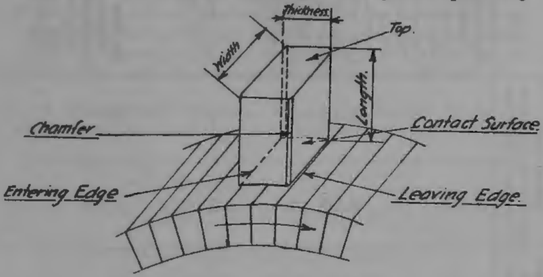


Fig. 84.—Nomenclature.

On non-interpole machines the movement from the neutral position will be in the opposite direction. The brushes on a motor will be a little behind the neutral position, and the brushes on a generator a little in front. This brings the coil undergoing commutation within the fringe of a magnetic field suitable in direction to assist in the sparkless reversal of the current, which must occur at all loads if the machine is to comply with B.S.S. 168.

4. Angle of Brush to Commutator.—Brushes are described as being " radial " when their centre line is radial to the commutator (Fig. 85 (*a*)), " trailing " when they are mounted at an angle inclined with the rotation (Fig. 85 (*b*)), and

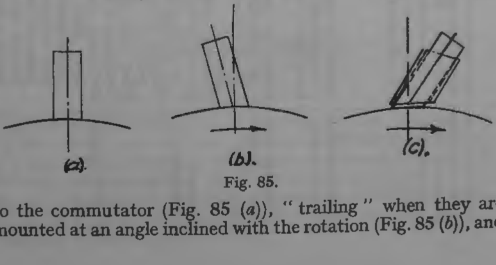


Fig. 85.

TABLE ZA.—*Types of carbon brushes.*

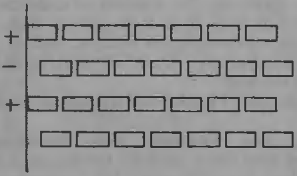
Type.	Remarks.	Contact drop per brush. Volts.	Current density per sq. inch.		Uses.
			Comm.	Slip rings.	
1. *Pure Graphite.* (Morganite and hard morganite.)	Made from pure plumbago suitably heat treated. High electrical and thermal conductivity. Superior lubricating properties. Comparatively soft. Coefficient of friction 0·12 to 0·17.	0·8 to 0·9	60 to 65	85	Especially suitable for rotary converter commutators, rotary converter and induction motor slip rings, but are of course suitable for most stationary machines, especially those running at high speeds. Silent running.
2. *Metal Graphite.* (Copper morganite.)	Mixture of copper and carbon in varying proportions. Coefficient of friction 0·18 to 0·2.	0·25 to 0·7	50 to 100	70 to 150	Low voltage D.C. generators (essential below 15 volts). Mica recessed. Rotary convertor slip rings.
3. *Graphite Carbon.* (Battersea.)	Mixture of pure graphite, retort carbon, and lampblack in varying proportions. Hard, robust, good lubricating properties. Coefficient of friction 0·2 to 0·23.	0·8 to 1·0	65	—	D.C. generators and motors with mica recessed.
4. *Carbon.* (Battersea.)	Mixture of retort carbon and lampblack in varying proportions. Cheapest type and suitable for most service purposes. Hard, dense, slightly abrasive. Coefficient of friction 0·27 to 0·3.	0·9 to 1·2	35 to 60	—	D.C. generators and motors with mica flush.
5. *Electro-graphitic.*	Essentially pure carbon brushes which have been raised to a very high temperature in the electric furnace and thus rendered graphitic. Retain hard, dense, and pure characteristics of carbon brushes and combine with these a highly lubricating nature. Electrical and thermal conductivity also increased. Capable of carrying heavy overloads and of resisting mechanical shock. Coefficient of friction [illegible] to [illegible]	0·85 to 0·9	55 to 65	—	Traction motors with mica recessed. Especially suitable for contacts subjected to violent sparking and severe mechanical shocks.

" reaction," or leading, when mounted at an angle against the rotation (Fig. 85 (*c*)).

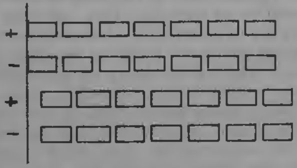
The setting is of course a matter of design, but the exact arrangement of the brushes in a machine must be carefully noted before brush-holders are removed from the rockers for cleaning or other purposes.

In this country brushes are usually set trailing (except on reversible machines), the angle from the radial being from 5° to 15°. In America reaction brushes are met much more commonly than in England, and the reason for their successful operation appears to be due to the fact that they are set at a very large angle from the radial, viz. between 35° and 40°.

5. Staggering Brushes.—The brush-holders should be arranged so that the brushes are staggered, to prevent, as far as possible, the formation of grooves in the commutator. Fig. 86 shows the correct and incorrect methods of staggering. It is impossible to explain fully here, but it may be said that the rate of commutator wear under the negative brushes tends to be greater than under the positive, and it is therefore better to arrange that both positive and negative brushes sweep the same tracks.



Incorrect Staggering.



Correct Staggering

Fig. 86.

6. Brush Pressure.—It is important that the pressure applied to the various brushes of a set should be made as uniform as possible, to ensure equal distribution of the current.

For small machines with no particular responsibility upon them, judging the pressure by hand may be good enough, but it is always advisable to use a suitable spring balance hooked into the pigtail. Care must be exercised to see that the balance is held in correct alignment, so as to get a true reading of the pressure. To determine exactly when the brush is released, a piece of paper may be slipped between the commutator and brush. A gentle pull on this will show when the grip is released, and the reading on the balance is to be noted. Alternatively, a cell and galvo may be connected between commutator and brush, and the balance reading noted when the circuit is broken.

Generally speaking, for stationary machines the brush pressure should be from 1½ to 2 lbs. per sq. inch. More than this may cause overheating by friction, and in all cases the lightest pressure at which a brush will work sparklessly should be considered the best.

On traction motors from 3 to 6 lbs. per sq. inch is required.

7. Fitting and Bedding New Brushes. — Brushes naturally work best when carefully bedded on a perfectly true commutator free from vibration, but to secure this state of affairs is not always an easy matter. The moving parts of brush-holders should be as light as possible and a suitable spring tension applied, and in the case of box-type holders, the brush should be an easy fit. The " sticking " of brushes in their holders is a frequent cause of unsatisfactory operation. Attention to these points will facilitate the slight up and down radial movement which is necessary for satisfactory working.

Bedding the brushes to the commutator can be done with the aid of a piece of carborundum cloth as indicated in Fig. 87.

The springs should be adjusted to a moderately heavy tension and the carborundum cloth drawn backwards and forwards until the brush assumes the required curvature. When the process is nearly completed, fine glass-paper should be used, and it should be pulled across the face of the brush in the direction of rotation only.

Emery should not be used, as, if embedded in the mica between segments, appreciable surface leakage may result. Glass and carborundum are better insulators.

After bedding, take out every brush from its holder and carefully remove every trace of dust from commutator, brushes, and holders. Take special care to see that there are no specks of carborundum embedded in the brush face.

Remember that, apart from defective bedding or spring adjustment, new brushes are apt to run less satisfactorily than the worn-out set just removed, because they are longer and less stable than the old ones, and because for the same reason they possess more inertia. Moreover, however carefully the bedding is done, it is impossible to obtain a perfect contact surface by grinding, and the final development of the surface must take place under normal running conditions. If possible, the machine should be run light for some time to improve the contact surface, and the brushes and their holders cleaned again. Remember that more dust is produced during the initial working life of new brushes than later on, and pay greater attention to cleaning accordingly.

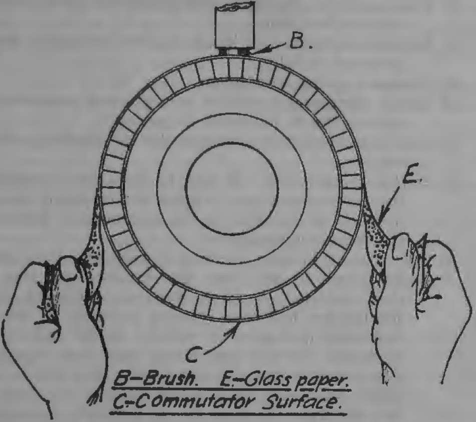


Fig. 87.

8. Chattering of Brushes.—Chattering of the brushes may be due to a variety of causes (among which are those detailed below).

The amount of vibration may be judged roughly by resting the tips of the finger nails lightly on the bearing caps and other stationary parts of the machine; also by holding a lead pencil lightly on the tops of the brushes in turn, right across one spindle, taking care not to receive a shock through the lead. It is not sufficient to feel one brush only, as the first one felt may be running quite smoothly, whereas some of the others may be chattering quite badly, due to roughness on the commutator or other cause. If the brushes chatter badly, chipping at the edges may occur, or even complete fracture, although the latter seldom happens except in traction motors.

Some possible causes of chattering :—

(*a*) High mica.
(*b*) Recessed mica, especially if the segment pitch is small and brushes thin.
(*c*) Excessive clearance in brush holders, especially when mounted radially.
(*d*) Incorrect spring adjustment.
(*e*) Rough commutator surface or a grooved commutator surface due to incorrect staggering.
(*f*) Loose commutator segments due to slacking off of end ring.
(*g*) Sticky commutator. If due to this cause, cleaning the commutator and brushes and applying a very little oil or vaseline to the commutator will stop the trouble immediately.
(*h*) One or more brushes jammed in holders. Care must be taken to see that the brushes are free in their holders. A large dynamo equipped with 100 brushes had been running perfectly for weeks. Suddenly it began to vibrate badly and spark violently. It was shut down, and close examination revealed that the cause was solely due to one brush becoming stuck in its holder. As soon as this was freed the machine ran perfectly as before.
(*i*) Brush-holders touching.

In extreme cases of machine vibration chattering may be eliminated by replacing the brushes by others of a more graphitic nature (*see* Table **ZA**).

9. Screeching of Brushes.—Screeching, singing, or hissing is generally accompanied by heating and undue wear, and it should therefore be stopped as early as possible.

It may possibly be due to hard or gritty brushes or to excessive brush pressure, but when a machine which has hitherto run silently suddenly develops screeching it will almost invariably be due to accumulated dust, either from the atmosphere of the dynamo room or from the brushes due to ordinary wear.

Wiping the commutator with a clean, dry, white rag (not waste) will often silence screeching, or in extreme cases a mere trace of mineral oil, vaseline, or graphite may be used to stop the noise. Very little commutator dressing should be used, as it will collect dust and particles of copper and carbon and thereby introduce further troubles.

103. *Commutators.*

1. Of all the components of a dynamo or motor it is the commutator that is most likely to be a source of trouble, owing to its comparatively fragile construction.

Should any looseness develop, as may be caused by the shrinkage of the insulation or loosening of the end nut, the whole structure becomes very weak, and its true cylindrical shape is lost, with the result that the brushes jump and destructive sparking occurs.

A short circuit may develop between adjacent segments of the commutator owing to some fault in the mica, to the accumulation of copper or carbon dust, or to solder running down the back of the commutator risers when sweating in the armature connections. Whatever the cause, the result will be overheating, and probably the burning out of the armature coil connected to the particular segments.

Pitted mica segments should be repaired as soon as discovered. The hole should be carefully cleaned out and filled with an insulating paste. A special mica cement can be obtained for this purpose, but a mixture of powdered mica and shellac varnish has been used successfully.

2. **High Mica.**—If the mica (or micanite) is too hard it does not wear away at the same rate as the copper, and in course of time it will stand above the copper and prevent the brushes from bedding properly, and so set up sparking. It is exceedingly difficult to be quite certain that the mica is absolutely flush, and is not projecting a fraction of a mil, which is all that is necessary to disturb the brush and prevent it from making intimate contact with the segments.

For this reason it is better to recess the mica when trouble from this cause is suspected.

Recessed mica will seldom be found necessary in machines of small size (below 50 H.P.), but in large machines and in very high speed machines it is almost essential. The work must be well done, however, or the results may be worse than before. The depth of groove should not be greater than the thickness of the mica, and the latter should be cleanly removed so as to leave a groove, rectangular in section (*see* Fig. 88 (*a*)). The edges of the copper segments should be bevelled with a well-worn smooth file.

If there is oily vapour present, or any special conditions which increase the risk of dirt sticking in the slots, the depth of the latter may be made equal to, say, half the mica thickness only.

Various tools for recessing mica, both power- and hand-driven, are on the market, most of which make a " V "-shaped slot (Fig. 88 (*b*)), which is considered by some engineers to be better than a rectangular slot.

This is debatable, but for service purposes very good work can be done with the home-made tool illustrated in Fig. 89, which makes a rectangular slot.

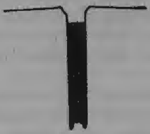


Fig. 88 (*a*).

Fig. 88 (*b*).

It consists of a short length of hack-saw blade secured in a piece of flattened tubing, the other end of which is fixed in a wooden handle. The latter should be substantial, otherwise the operation becomes tiring. It is advisable to keep the tube back about half an inch from the tip of the saw, as illustrated, so that it does not obstruct the view of the mica.

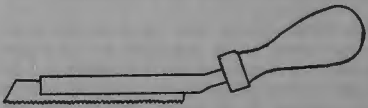
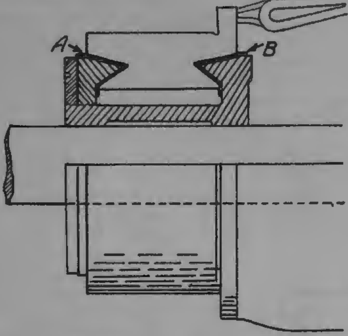


Fig. 89.—Mica slotting saw.

3. Commutator Wear.—The wear of commutators (and slip rings) is due to three causes: mechanical abrasion, a burning action, and a quasi-electrolytic or arc effect which causes a transference of metal in the direction of the current (at the negative brush). Normally, if the commutator is kept clean, the correct type of brushes used, properly staggered, the commutator will assume a dark chocolate-coloured appearance, and the rate of wear will be very small indeed. It is difficult to attach too much importance to the polish of commutators, but it cannot be too strongly emphasized that it must occur in ordinary normal wear, and on no account must sandpaper or other abrasives be used in the mistaken idea that a bright metal polish is necessary.

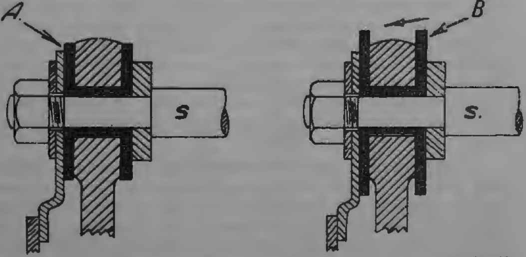
If the commutator is not perfectly smooth and polished large quantities of almost invisible metallic and carbon dust are worn from the commutator and brushes. These become deposited in the interior of the machine and on such places as the windings, the insulation at the back of commutators

(Fig. 90), and on the insulation of the brush-holder spindles (Fig. 91), and frequently cause breakdowns. A large proportion of breakdowns of electrical machines would not have occurred if the commutators had been kept clean.



A–Front Leakage path. B–Back Leakage path

Fig. 90.



A.–Insulating Washer of poor design S.–Brush spindle.
B–Correct type of Washer.

Fig. 91.

At intervals depending upon the service and the location, the commutator contact surface and end should be thoroughly wiped with a clean cloth that is free from lint. Lubrication should be very sparingly used on a commutator, and no grease, oil, or dirt should be allowed to accumulate on the commutator or the brushes.

Leakage of oil from a bearing on to the commutator is dangerous, and should be stopped. In some cases with oil-ring lubrication the oil has been known to pass along the shaft under the commutator, and then be thrown out by centrifugal force through the commutator on to the surface. To obviate this an oil-thrower should be fitted (*see* Fig. 92).

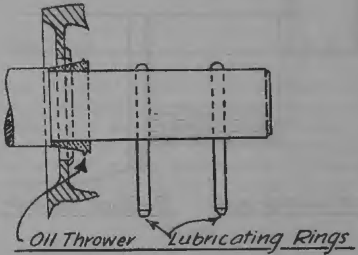


Fig. 92.

4. **Eccentricity.**— In actual practice one often finds that commutators are slightly eccentric. This does no harm in machines of moderate speed if the brush gear is properly designed, because the brushes in rising and falling as the commutator goes round at a speed from 10 to 15 revs. per sec. can keep in close contact with it.

Appreciable eccentricity, however, due to bearing wear or to slackening of the commutator end rings must be corrected if sparking is to be prevented.

5. **Distortion. Loose Commutator Segments (High and Low).**—This may be due to shrinkage of the mica insulation, resulting in a slackening off of the end rings. It can sometimes be corrected by screwing up the end ring (or clamping bolts) when the commutator is hot. If this is not sufficient the commutator must be removed from the armature and tightened in a press. This involves the disconnection and reconnection of the armature leads, and the work must be done in a repair shop. Fortunately, such extreme measures are seldom necessary with small commutators.

6. **Out of Balance.**—Brushes cannot maintain contact

with a commutator or slip ring that is out of balance, and sparking inevitably follows. This is, of course, a question of design, and does not usually concern the operating engineer after the " acceptance " testing.

7. **Vibration** is a frequent cause of trouble, and may be due to insufficient rigidity in the foundation block or attachment, to wear in the bearings, to a loosely-keyed pulley, to out of balance or other causes.

8. **Low Bars or Flats.**—" Flat " is the name given to a hollow or sunk segment (or segments) in the commutator which appears to have worn away more quickly than the rest. In modern machines " flats " are not so common as they were formerly. They may be the result of many causes, among which are the following :—

(*a*) Intermittent overloads or temporary short circuits.
(*b*) Accumulation of oil and dirt.
(*c*) Bad joint in belt.
(*d*) High mica.
(*e*) Faulty connection between armature winding and commutator. This is sometimes difficult to detect, but the joint should be resoldered if suspected. Silver solder should be used.
(*f*) Segments low to a minute extent when first received from manufacturers.

9. Whatever the cause, when once a flat is started it naturally grows, as the burning action of the arc effect becomes accentuated when the contact is indifferent, and this causes more rapid wear than mere mechanical abrasion. It will be clear therefore that the abrasive action of the brushes will not automatically correct the defect, as may appear at first sight.

Fig. 93.

It must be emphasized that the device illustrated in Fig. 95 is quite useless for removing even an incipient flat. If not too far gone it can be removed with a commutator stone (Fig. 93), provided that the circumferential dimension of the latter is comparatively large and the stone accurately shaped to the same radius as the commutator.

These so-called "Commstones" grind under full speed operating conditions, the material being a perfect insulator, and they may be safely used on 250 volt machines operating at full load. With care 500 volt machines can also be ground when working. The length of the stone should be as great as will allow it to work between adjacent brush sets "A" (Fig. 94), but narrow enough to be moved backwards and forwards slowly across "L." (The stone should be at least twice as long as the width of the flat.) When ordering, give width of commutator "L," distance between adjacent brush sets "A," and approximate diameter "D." These stones can be obtained in two grades, one for rough work and one for finishing.

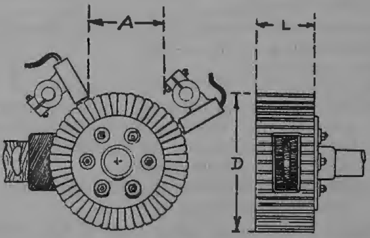


Fig. 94.

Generally speaking, if the flat has developed beyond the very early stages, turning or grinding is inevitable.

In the case of large machines it is better to do the grinding with the armature in its own bearings, and special grinders can be obtained for the purpose.

They take the form of a small slide rest with grinding wheel attached to an electric motor fixed to the traversing slide. The brushes are all removed and the commutator is revolved very slowly whilst the grinding wheel is traversed very slowly across its surface. A grinding wheel of special material is used, its surface speed is about 3,000–4,000 ft. per min., and the work feed not more than 1 foot per 5 secs.

For small machines it is generally more convenient to take the armature out and turn the commutator in a lathe. This should present no difficulty beyond the mechanical injury the machine is likely to sustain in inexperienced hands. The most likely damage is that arising from pressure or knocking the end windings down when getting it into the lathe centres.

The best way of handling the armature is to lift it in a rope sling with a spreader, by a portable crane, and drop it down to the lathe centre height. Care is necessary to ensure that the commutator does not get a blow, as it might result in one or more of the copper segments being driven in and so cause internal trouble; also the armature windings must be carefully protected with canvas, to prevent the entry of dust or turnings.

The drive should be from the pulley end, to prevent damage to journal portions of the shaft.

The housings of ball or roller bearings should not be removed, unless absolutely unavoidable.

A fine-pointed tool—about 55°—should be used, with plenty of side rake, and a very slow feed. A broad tool must not be used, as it sets up chattering, and is more liable to burr over the segments. Several light cuts are preferable to a few heavy ones, and the job is best worked dry, without any lubricant, and at the same surface speed as for cast-iron. The finishing cut should be as light as possible, with an oilstone finish on the tool point and the speed a little higher.

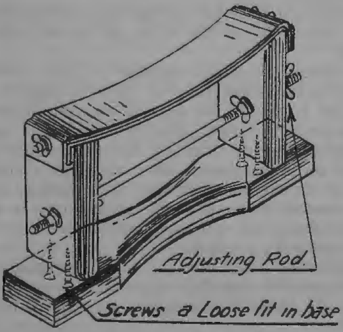


Fig. 95.

When the turning or grinding is finished, the surface should be thoroughly polished with very fine glass-paper. A convenient form of holder is illustrated in Fig. 95. The mica should then be carefully examined and assurance made that no particles of copper have been dragged over from one segment to another, or become embedded in the mica.

When reassembling the brush gear, see that the brushes go back into the same holders again, and in the same relative position.

104. *Armatures.*

1. Apart from purely mechanical reasons, such as the armature rubbing on pole pieces due to eccentricity or heat conducted from a hot bearing, the following are the principal reasons for the overheating of armatures :—

(*a*) Overload.
(*b*) Sparking at brushes.
(*c*) Leakage to earth.
(*d*) Short circuits.

2. **Leakage to Earth.**—If the insulation resistance of a machine as a whole is low, the brushes should first be raised, and the insulation of the field, armature, and brush rockers tested separately.

When measuring the I.R. of the armature separately, the earth lead should be on the shaft, to obviate error due to bearing oil.

A not unusual cause of trouble is faulty insulation or surface dirt on the brush rockers. If the leakage is definitely traced to the armature, the ends of the commutator should first be suspected. Copper dust or carbonized oil may be lodged between the end rings and the commutator segments. If there is no improvement after thoroughly cleaning the armature, it should be dried out. The surface area of the armature winding in contact with the iron core is very large, and general dampness will frequently cause a " zero " test to be obtained with a megger.

Oil sometimes soaks into the insulating material, which in course of time becomes charred, and therefore of much lower resistance. In these circumstances a complete rewind may be necessary.

If, however, a definite earth fault persists when the armature is quite clean and dry, an endeavour should be made to locate the trouble, although it is not at all an easy matter, owing to the continuous nature of the winding.

The armature should be removed from its field and placed on a trestle or cradle, and one of the following tests applied.

i. Pass a current (not exceeding the normal full-load current) from the armature to the shaft, *i.e.*, make one connection to a commutator segment and the other to the shaft. Hold a compass needle in one position while the armature is slowly turned round.

If the connections remain undisturbed, a point will be reached at which the compass needle will reverse. This indicates the proximity of the earthed conductor. This conductor should be marked and the experiment repeated, but with the current led into a different segment. If the experiment be successful, the reversal will again occur at the marked conductor.

ii. Pass a current (not exceeding normal full-load current) through the armature, making contact at the normal brush positions. This may be done by means of brushes fixed to a temporary rocker or the connections may be clamped or soldered on. One lead from a testing voltmeter should then be connected to the armature shaft, and the other held against each commutator segment in turn till no deflection is obtained. This will be the earthed section. As the deflections obtained on the neighbouring sections will be very slight, the travelling connection should be moved first to one side then to the other of the zero position to segments giving equal deflections on either side. The earthed section will be midway between the extreme right and left segments touched. The connections are similar to those in Fig. 96, except that one lead from the voltmeter is to be connected to the shaft instead of to a brush.

If a millivoltmeter be available, a quite small testing current will suffice.

If there is more than one fault or the resistance of the fault is too high, the above methods may not be very successful, and the best plan is then to break the armature winding up into two parts by unsweating the end connections to the commutator, find out which half the fault is in, then break that part up into two, and so on until the fault is found.

If the fault is in the upper layer of armature conductors it may be possible to remove the binding wire, raise the conductor, and reinsulate.

If a machine is allowed to race and the binding wire breaks it may fracture into a number of small pieces, which become embedded in the armature winding by rubbing on the poles.

In these circumstances it is frequently necessary to remove all the armature conductors and retape.

3. **Intermittent Earth on Armature.**—Occasionally an "intermittent" earth may give trouble, making contact only when the machine is running. This might be suspected if any of the coils appear to be loose, or if "pitting" occurs at the bearings.

4. **Short Circuits.**—A very damp armature may show short-circuit symptoms, and cause the machine to take an excessive current even when running light.

When a definite short circuit occurs in an armature coil of a machine in operation it does not usually require much searching for, because it becomes very hot and the symptoms are first a smell of burnt insulation, then smoke, coupled sometimes with bad sparking.

Although the short circuit may occur between the turns of the coil itself, it is more commonly found to be between the end wires at or near the commutator or in the commutator itself.

Burred-over commutator segments, solder dropped behind the commutator risers when the armature conductors are sweated in, are common causes of short circuits, others are copper and carbon dust, oil and dampness.

If the insulation is badly charred there is nothing for it but to put in a new coil. The copper wire will usually be too brittle to use again.

It will frequently be possible, however, to detect incipient short-circuit conditions before the consequent heating becomes destructive, and when there is any doubt about it, a short-circuited coil may be located as follows :—

Disconnect the field winding and pass a current through the armature in the usual way. If a voltmeter is connected between each pair of adjacent segments in turn the deflections obtained should be approximately uniform throughout. Any appreciably reduced deflection will point to a short-circuited coil. If a millivoltmeter is available, quite a small current is sufficient for testing purposes. *See* Fig. 96.

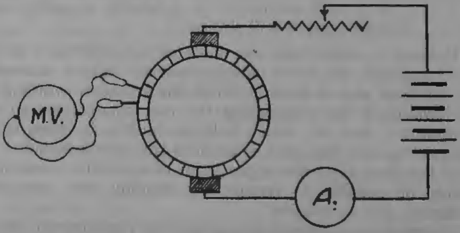


Fig. 96.

If the cause of the fault cannot be located by visual inspection, the particular armature coil should be unsweated from the commutator, and commutator and coil tested separately.

5. **Temporary Repairs.**—It may sometimes be essential to keep a machine running at all costs, when there is no time to rewind a coil. In such a case a temporary repair may be effected by disconnecting both ends of the defective coil

(or series of coils in a wave-wound machine) from the commutator and then short-circuiting the two commutator segments to which it was connected by means of a copper wire or strip soldered to the risers. A machine patched up in this way may do the work required of it satisfactorily for an indefinite time.

6. **Breaks or Bad Joints.**—When there is a break in an armature coil sparking is usually very bad, amounting frequently to flashing over between brushes. If the machine has been allowed to run for any appreciable time in this condition a bad flat will be obvious, and the mica between the segments to which the faulty coil is connected will be badly burnt. In a wave-wound armature the commutator will be burnt at as many different points as there are pairs of poles.

If there is any doubt about the matter and the existence of a bad joint or break is suspected, it may be located as follows :—

With connections as in Fig. 96, assume one coil broken in the left half of the armature. The millivoltmeter readings on the right half of the armature will be uniform and low, but on the left half the instrument will read zero except when the contacts are on the segments between which the broken coil is connected, when the reading will be relatively high.

Apart from mechanical damage, a break seldom occurs in the coil itself. It is much more likely to be found in or near the joints between the armature conductors and the commutator risers. The coil may have been overheated, due to prolonged overloads, and the solder may have run. The obvious remedy is to resolder the joints, using silver solder and an alcoholic solution of resin as a flux, thoroughly tinning the parts before they are brought together. It may not be superfluous to point out that soldered joints that appear good on the surface are not necessarily good right through, and to ensure that they shall be thorough, a blowlamp may sometimes be used with advantage to maintain the parts at a proper temperature, the soldering iron serving chiefly to direct the flow of solder.

7. **Armature Coil Repairs.**—A job which involves the removal of armature conductors from the slots should not be lightly undertaken. Fortunately it is not often necessary.

The new conductors and insulation must be of exactly the same dimensions and material as those replaced, and herein lies one of the difficulties of undertaking repairs locally. The original design naturally provides for a close fit in the slots, and it will very seldom be practicable to extemporize with materials of dimensions differing from those originally fitted. Moreover, military personnel will seldom get sufficient practice to maintain a high enough standard of manual dexterity as armature winders (except perhaps in the case of quite small machines such as fan motors).

In England, therefore, under peace conditions, it is preferable to return an armature to the makers or to send it to one of the many firms who specialize in armature repairs.

If it is decided on grounds of expediency to attempt repairs locally, the following remarks may be helpful.

Except in the case of very large or small machines, armature coils are invariably former wound. The wires (or rectangular strips) forming such coils are wound together on a former of special shape, the finished coils being perfectly symmetrical and interchangeable.

Small wires of circular cross section are insulated with a double cotton covering, and the larger conductors of rectangular cross section with linen or cotton tape. The finished coils are varnished and then linen taped before insertion in the slots. When the whole winding is completed and the binding wires have been put on, the armature is treated in a vacuum-drying and impregnating plant.

To replace a former-wound coil it is necessary to lift a number of sound coils before the defective one can be removed.

Each coil usually has its straight portions placed so that one is at the bottom of the slot and the other at the top of the slot, that is, they are alternately in the lower and upper layers.

To remove a coil, commence by lifting the upper conductors from every slot, extending along the circumference for a distance equal to the span of the damaged coil, which can then be loosened and lifted out. If the copper conductors are not badly damaged the coil can then be taped up again and replaced.

The whole of the coil must be retaped—patching is unsatisfactory.

Unless the machine is a comparatively new one, it will usually be wise to retape all the coil sides and ends which have been displaced, as it is almost impossible to ensure that the insulation is not damaged when coils are removed.

The above is the minimum essential work, but it is really better when committed to disturbing a number of the coils to remove and retape the whole armature winding.

If the conductors are found to be burnt out or brittle or badly pitted through fusing, completely new coils should be fitted. It is preferable to obtain these coils from the manufacturers.

Large machines are usually bar wound, and will not be further considered.

Small machines, including fan motors and the like, are usually hand wound, and as the coils necessarily overlap at the ends, the replacement of a single coil frequently involves the removal of the greater portion of the winding. Notwithstanding this, repairs to such machines present fewer difficulties than repairs to the larger former-wound machines. Sometimes a damaged coil may be cut through and removed without the necessity for unwinding turn by turn, and the new coil wound over the sound ones. The wires in these small machines are frequently insulated with silk or enamel instead of cotton.

Slots are lined with mica, micanite, presspahn, or other insulating material, which completely encases the coils. This lining is frequently reinforced with mica at the ends, where the coils bend over the sharp edges of the slots, as these are the parts where damage to the insulation is most likely when the coils are being tapped into place. The slot lining where bent over to meet at the top of the slot should not be more than $\frac{1}{32}$ in. above the surface of the armature core before the binding wire is applied. On the other hand, it may be necessary to insert a strip of vulcanized fibre or presspahn to bring up the level of the insulation to the periphery.

When coils are removed the slot linings must always be renewed.

When the coil winding is completed and the binding wire renewed, the armature must be thoroughly baked at 200° to 220° F. to get rid of moisture, and then treated with a good air-drying insulating varnish. Dipping is, of course, preferable, but may not always be practicable. Simple brushing on is not so satisfactory, but if the varnish is carefully and copiously applied while the armature is hot and dry, and subsequently baked at about 180° F. for about eight hours, the job can generally be relied upon.

Vacuum drying and impregnating plant will rarely be available at stations, but insulating varnishes can be obtained suitable for air drying or for baking in an improvised oven, which can be made up locally of sheet iron and heated with carbon lamps or resistance coils.

8. **Banding of Armatures.**—In small machines, such as fan motors, the armature conductors are usually kept in place by wood or fibre wedges, the slots being suitably shaped to take them. The ends of the windings are usually bound with whipcord.

But in most cases likely to be met with in the service the centrifugal and electrical forces are dealt with by tinned-steel piano-wire bands wound on mica strips, to prevent the wires from cutting into the coil insulation, and also to prevent solder from running through.

Replacing bands is not a difficult operation, but it is often done in a slipshod manner. If the bands are not tight, the resultant movement of the coils will eventually wear the insulation and cause earths or shorts, or open circuits may occur due to the armature conductors breaking at the points where they are soldered to the commutator risers.

Where a proper banding machine is not available, there are several methods in use of applying the tension to the wire. One involves the use of an ordinary lathe fitted with a friction brake. In another the armature is mounted on trestles, and a crank handle fixed to the shaft extension.

A mica strip is first put on and secured by a temporary binding just clear of the position to be occupied by the permanent binding. The coil of binding wire is then placed in a convenient position, and the end of the wire secured to the armature by a fibre pillar in one of the slots, or in some other way. The required number of turns are then wound on as tightly as possible, and the running end firmly secured.

A number of sheet-tin or german silver strips (Fig. 97) are then slipped under the wires every 3 or 4 inches.

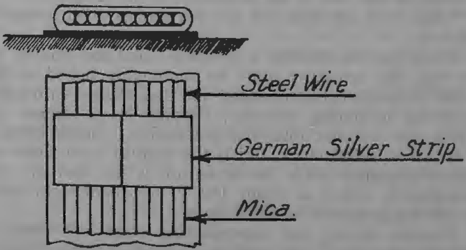


Fig. 97.

At this stage the tension in the wire will not usually be sufficient, but it can be increased as follows :—

Slip a steel hook under the first turn at the front end, run it round into the horizontal position as shown in Fig. 98. One man then pulls steadily on the hook while the other rotates the armature in the direction shown by the arrow. The hook thus passes under all the turns and the tension on the wire is considerably increased. When approaching the end of the last turn, one man keeps the tension applied while the other solders all the turns together on the outer side of the loop, which can then be cut away. The turns can then be soldered across near the end of the first turn. The german silver strips can then be bent over and soldered down, and the soldering continued right round the band.

The sizes of binding wire most commonly used are from 22 to 18 S.W.G.

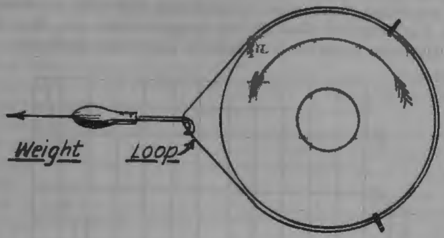


Fig. 98.

The tension to be applied is about 100,000 lbs. sq. inch., that is, say, 200 lbs. for 18 S.W.G wire on the core bands. The tension on the end bands should be 10–20 per cent. less.

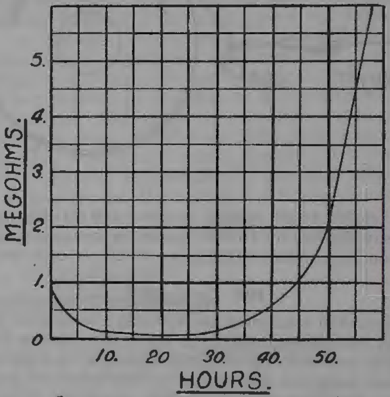
105. *Drying Out.*

All electrical machinery not specially constructed to resist injury by moisture must be kept dry. If a machine has been exposed to moisture, the windings should be thoroughly dried out before being put into service. This is true of nearly all machines that have been in storage, especially in unheated warehouses, or machines that have been idle for some time; it is particularly true of new machines that have been long in transit.

So long as a machine is in normal service and has its temperature kept above that of the surrounding air, trouble due to moisture is unlikely, and the impregnating and coating varnishes will tend to keep out moisture during the short intervals when the machine is not running. But however well the impregnation is done, cotton and paper will absorb moisture if exposed to a humid atmosphere for long periods.

When once moisture has got into a well-varnished armature it is a rather difficult matter to get it out. Heating the armature at first merely has the effect of evaporating the moisture in one part of the coil and driving it into another part. Sometimes the moisture which is in the pores of the cotton is driven to the surface, where it is more effective in reducing the insulation resistance. This is seen by the way in which the insulation resistance of a damp machine falls when it is first warmed up.

If a machine is fairly dry, its insulation, when cold, will always be much higher than when hot. This effect is most commonly due to the way in which the residual moisture distributes itself in a hot machine, though, apart from this, the insulating resistances of insulating materials are lower at high temperatures than at low temperatures, *i.e.*, they have a fairly large negative temperature resistance coefficient.



Curve showing change of insulation resistance during the drying-out period.

Fig. 99.

The best method of drying out small machines is to heat them up in a vacuum oven, but the moisture can be got rid of satisfactorily by air circulation in an improvised oven if the temperature is maintained at from 200° to 220° F. for a long period, the air is dry, and a good circulation is provided for. The temperature should be raised gradually, several hours being required, depending on the size of the machine, and should be as nearly uniform as possible throughout the windings. The temperature should remain constant for a period varying from one day to one week, depending on the size and voltage of the machine.

Alternatively, a dynamo may be dried electrically as follows :—

Drive the machine at normal speed, with a very low, separate excitation (about one-twentieth to one-tenth of its normal value). Short circuit the armature through an ammeter and adjust the armature current to between 50 and 100 per cent. in excess of the normal full-load current, depending on the size of the machine. It is better to start with 50 per cent. excess current and shut down, and measure surface temperature of armature after an hour or so to ensure that the maximum safe temperature is not exceeded. A surface temperature of about 180° F. should not be exceeded. The temperature of certain embedded portions will no doubt exceed this value by 20–30 degrees.

A motor may be dried electrically by applying a low voltage to its terminals. The voltage should then be raised until the armature takes from 50 to 200 per cent. of normal full-load current. Care must be taken that the machine does not run at a speed in excess of normal speed, or, alternatively, the armature may be locked.

If it is not convenient to apply one of the above methods, the armature may be removed from the machine and a current passed through it from a low-voltage supply.

The drawback to the electrical methods is that one part of the winding may become too hot before another part has been heated up enough to get rid of the moisture.

The guiding points are (1) the temperature of the cotton, linen, or paper insulation must not exceed 220° F. at any part, and (2) the surface temperature as measured by a thermometer may be 20° to 30° lower than that of the hottest spot in the windings.

The drying out process may take several days, but it must not be unduly hurried by permitting an excessive temperature.

The insulation resistance should be measured from time to time to ascertain progress (*see* Fig. 99).

CHAPTER XV.

SECONDARY BATTERIES.

106. *General considerations.*

1. A secondary battery, known also as an accumulator or storage battery, is an apparatus capable of receiving electrical energy and giving it out again when required. The electrical energy received during charge is transformed into chemical energy, and a large portion of the latter is recoverable in the form of electrical energy during discharge.

Such batteries are of two main types, fixed and portable. In this chapter the former are more particularly dealt with, though the general principles are equally applicable to the latter.

2. **Uses.**—The advantages of such an apparatus are numerous. The generating plant may be shut down during periods of light load, or when running may be inconvenient, *e.g.*, at night. The batteries may also be made to discharge in parallel with the generator during periods of exceptional load; and their presence will ensure, at any rate for some hours, a continuity of supply during a shut-down of the generating plant caused by a breakdown or necessity for repair. The batteries can also be used in series with the generator if so desired, but the greatest care must invariably be taken to ensure that the battery is not over-discharged nor over-charged.

3. **Types of cells.**—Although the electro-chemical transformation may be accomplished by a large number of different types of cells, the cell in general use in the Service is the **lead** type. The **Edison** (iron-nickel oxide) type, which has been used considerably and possesses some advantages over the lead cell, is further discussed in Sec. **120.**

4. The **lead cell** consists of a number of lead plates immersed in dilute sulphuric acid, the positives being coated with lead peroxide and the negatives with pure lead in a spongy form. The success of the lead secondary cell is due chiefly to its very low internal resistance, its steady and high E.M.F. during the greater part of discharge, and its moderately high efficiency, *i.e.*, ratio of watts taken out to watts put it. On the other hand, its cost and weight are considerable, and it also requires careful use and steady work.

5. **Action of the lead cell.**—A lead cell, after charge, is capable of giving out electrical energy by virtue of the chemical reactions between the lead (negative plate), sul-

phuric acid (electrolyte), and lead peroxide (positive plate). Whatever may be the precise nature of these reactions, the effect is that during discharge a part of the sulphuric acid in the electrolyte is reduced, and lead sulphate is formed on the plates. This has the double effect of lowering the terminal P.D. and also the specific gravity of the electrolyte. During charge, the reverse process takes place, the active material on the plates being desulphated and the specific gravity of the electrolyte being restored to its previous value. When desulphating is complete, the further passage of current produces electrolysis of the water in the electrolyte, and gas is given off at both plates. The cell is then fully charged.

6. **Life.**—The life of a battery is to be reckoned, not as a period of time, but as a number of cycles of charge and discharge. Thus, the practice, before trickle charging (*see* Sec. **114**) was introduced, of maintaining standby batteries by means of periodic charges and discharges, undoubtedly shortened their lives. A battery maintained by trickle charging and seldom used, should last almost indefinitely.

107. *Plates.*

1. The plates consist primarily of a framework or grid of lead, which should be as chemically pure as possible. Impurities give rise to corrosion and oxidation, and should not, as a rule, exceed 0·05 per cent. Copper is especially detrimental as it sets up a counter E.M.F., which prevents the cell taking its proper charge. The lead forming the grid is sometimes alloyed with antimony to give additional strength. Excessive quantities of antimony, however, are liable to cause brittleness and consequent cracking when the active material expands.

2. Plates are divided into two main types, **formed** and **pasted.**

i. **Formed plates.**—In this type, first produced by Planté and frequently called by his name, the active material is formed by electrolytic action from the grid or framework itself. If two plates of pure lead are immersed in dilute sulphuric acid and a current is passed through the electrolyte from plate to plate, the positive, *i.e.*, the plate by which the current enters, will become coated with a film of lead peroxide, while the other plate, the negative, will apparently remain unaltered, though in reality some of the lead will have been reduced to the pure spongy form. By repeated charging and discharging this film may be increased in thickness to the desired amount.

In order to hasten this somewhat tedious process of plain electrical formation in pure sulphuric acid, various methods, which are practically trade secrets of battery makers and involve the use of lead dissolving acids and other reagents, are adopted, and the plates are so designed as to present a larger active surface than that obtainable with a plain lead plate, thereby enabling more active material to be deposited during one charge.

ii. **Pasted plates,** as their name implies, have the active material in the form of paste forced into pockets in the lead grid, the difference in manufacture being that the early processes of formation electrically are avoided, as the active material is already partially formed when it is forced into the grid. Pasted plates, when made up in a cell, require a long initial charge at slow rate before the cell is put to work.

As regards the relative merits of the two processes, pasted plates are usually lighter than formed ones of the same capacity. The active material, moreover, adheres to the grid better in the latter than in the former type. So far as manufacture is concerned, pasted plates, requiring considerably less time than formed plates, are cheaper.

The general modern practice is to use formed plates for the positives and pasted plates for the negatives. Pasted positives are, however, used for traction work and in portable cells in order to save weight, and also for standby batteries, as they suffer less than pasted plates from absence of work.

3. **Positive plates.**

i. *Types.*—The following are the main types that will be met with in the Service :—

(*a*) *Faure plate.*—This is a pasted plate, consisting of a grid of lead alloyed with 5 to 10 per cent. of antimony in shelf, cage, or core form; as the grid is purely a support and takes no part in the chemical reactions, it can be constructed solely with a view to strength—hence the large amount of antimony. The shelves or cages are filled with active material, or the paste is held round a central core by means of an outer shield (Pl. **122**, Fig. **1**). These plates are in use in only very few stations.

(*b*) *Planté plate.*—This is a formed plate consisting of a casting of soft lead of very high purity, the surface of which is worked into a series of vertical or horizontal ribs (Pl. **122**, Fig. **2**). It is the standard plate now supplied.

(*c*) *Special Planté plate.*—In this type the frame is an alloy of lead with about 1⅓ per cent. antimony. The active material is formed from soft lead, similar to that used in ordinary Planté plates, fitted to the grids in the form of rosettes (Pl. **122**, Fig. 3). These plates are the heaviest of the three types and are only in use in a very few instances. This type of plate, if over-charged, will split rather than buckle, the latter being the tendency of the ordinary plate.

ii. *Formation.*—Positive plates are despatched from the battery makers' works in a lightly formed condition. This ensures that they are not over-formed at the end of the prolonged initial charge, which is necessary for the negative plates when the battery is first erected.

If the plates were too heavily formed before despatch, the additional forming given at the initial charge would cause them to be over-formed. The excessive layer of active material so formed would have little adhesive affinity to the lead base, and it would either fall down as a deposit on the floor of the cell or, by filling up the interstices of the positive plates, reduce their effective area and, consequently, the capacity of the cell. In either case the life of the cell would be curtailed.

An early shedding of active material may, therefore, be due to over-formation, or it may be the result of failure to free the plates from all traces of forming reagents before they leave the factory.

iii. *Appearance.*—A healthy Planté positive plate should have a rich chocolate colour when fully charged, should feel greasy when rubbed, its active material should adhere firmly to the grid, and there should be no scaling. The plate should be straight with no signs of distortion or buckling.

A special Planté plate will feel less smooth than one with no antimony alloyed with the lead.

4. Negative plates.

i. *Types.*—There are two types of negative plates in use, the *grid* and the *box* types.

(*a*) *The grid type negative.*—This consists of a cast frame filled with paste, the grids being shaped and cast in such a manner that the paste cannot fall out unless the plate is roughly used (Pl. **122**, Fig. 4).

(*b*) *The box type negative.*—This is now in general use in the Service and has proved satisfactory.

2. **Connecting bars.**—These are of lead and should be of ample section to carry the maximum current that may be demanded from the cells with an increase of temperature not exceeding 10° F. They are provided with suitable straps or lugs for bolting or burning to those of the adjacent cells.

3. **Containing vessels.**—The plates are contained in a box made either of glass, ebonite composition, or of wood (teak or pine), the last-named being lined with lead. The glass boxes are normally used in the Service at home stations for batteries of capacities up to **600Ah,** and the wood, lead-lined boxes for batteries of higher capacities at home stations and for all batteries supplied to foreign stations. The plates are suspended by the lugs from the sides of the glass boxes. In the case of wooden boxes, the plates are supported on glass hangers, and lead shoes or wooden rails are provided to prevent the sharp edges of the glass cutting into the boxes. The depth of the boxes is such that, when the plates are in position, there is a clear space of 3 inches between the bottom of the plates and the bottom of the box, and of 1½ inches between the tops of the plates and the top of the box. The former space allows all sediment to settle clear of the plates, avoids the danger of short-circuiting being caused by bridging plates of opposite polarity, and should be sufficient to contain all sediment formed during the normal life of the plates. The latter space ensures that the plates will be always kept well covered by the electrolyte, which is essential for their welfare.

4. **Separators.**—The plates are kept separated by glass rods or by very thin sheets of specially treated wood. Wood separators are the more satisfactory, as their use ensures that the plates cannot touch under any circumstances. They must not be allowed to get dry, and should be kept in distilled water until being put into use.

5. **Spray covers** are usually made of glass in one or two pieces and are placed on the top of the container to minimize the dispersal of acid spray.

6. **Anti-spray films.**—The introduction of a ⅛-inch film of oil on the top of the electrolyte in a secondary battery has several advantages :—

(1) Evaporation is prevented, with consequent saving of distilled water and labour required for "topping up."

(2) Acid spraying is prevented, with a possible reduction in installation costs, as special ventilating arrangements may be dispensed with, and the battery may be put in the same room as other plant.

It is essential that a highly refined paraffin oil be used;

the Post Office have standardized a quality marketed as "Blancol."

The disadvantages of oil films are the difficulty of taking hydrometer readings, and the liability of the oil to become opaque, in dusty situations and through impregnation of the carbon expander in the negative plates.

The use of oil is of most value in stand-by batteries where little gassing takes place. About 0·065 gallon is required for one square foot of surface.

Pl. **123** shows a typical secondary cell.

109. *Electrolyte.*

1. **Specific gravity.**—Electrolyte is prepared from pure sulphuric acid diluted with distilled water until it attains the required specific gravity. The strength of the acid is important; very weak acid and very strong acid both offer a higher resistance to the passage of an electric current than acid of medium strength. Moreover, the electrolytic decomposition of very weak acid has a different effect on the plates from that of stronger acid, and corrosion of the plates will result; in very strong electrolyte the plates would become badly sulphated.

During discharge the specific gravity of the electrolyte falls as the acid combines with the plates. On re-charging the active material is restored to its original condition, the acid being restored to the electrolyte, and, consequently, the specific gravity rises again to its original value. It is, therefore, necessary to make the mixture strong enough to be low in resistance, and not too weak at the end of discharge, but not sufficiently strong to run the risk of damaging the plates.

The actual densities used vary according to the size and capacity of battery, nature of separators, and other factors.

Portable and car batteries use acid of high S.G. The volume of electrolyte is small, as the plates are close together, and so to obtain sufficient SO_4 ions to utilize the plates to their full capacity, the S.G. must be high.

A usual figure for a stationary battery when fully charged is 1,210–1,215, and in the tropics 1,195–1,200 (the figures being for a temperature of 60° F. in both cases).

The specific gravity when the battery is fully discharged will be about 50 points lower.

Battery makers specify the correct densities of acid when supplying a battery, and the figures given must be rigorously adhered to.

2. **Effect of temperature changes.**—It must be noted that the specific gravity of the diluted acid varies with the

PLATE 123.

SECONDARY CELL.

temperature. If the temperature rises the electrolyte expands and its specific gravity decreases.

The variation is approximately 0·001 for every 2½° F. rise or fall of temperature. The standard temperature is taken as 15° C. or 60° F., and it is to acid at this temperature that the figures given in para. 1 refer. For other temperatures, a correction must be applied to the hydrometer reading to obtain the equivalent at the standard temperature. A chart from which the necessary corrections can be obtained should be put up in every battery room.

3. **Breaking down acid.**—At home stations, acid is supplied already diluted to the required density. At stations abroad, concentrated acid of 1·845 specific gravity is supplied, and this will require diluting, or breaking down, to the specific gravity given in the maintenance and erection table. This should be done in a lead-lined wooden tank, the acid being slowly poured into the water and thoroughly mixed by constant stirring. During this process there will be a considerable rise of temperature, and the electrolyte must not be poured into cells until it has cooled down to atmospheric temperature.

On no account must the electrolyte be mixed by pouring water into the acid.

4. **Purity.**—Absolutely pure sulphuric acid, and not the commercial variety, must be used as an electrolyte. Brimstone acid, *i.e.*, acid derived from sulphur, is often specified, but the essential point is that no impurities, such as iron, copper, or chlorine, should be present to any appreciable extent.

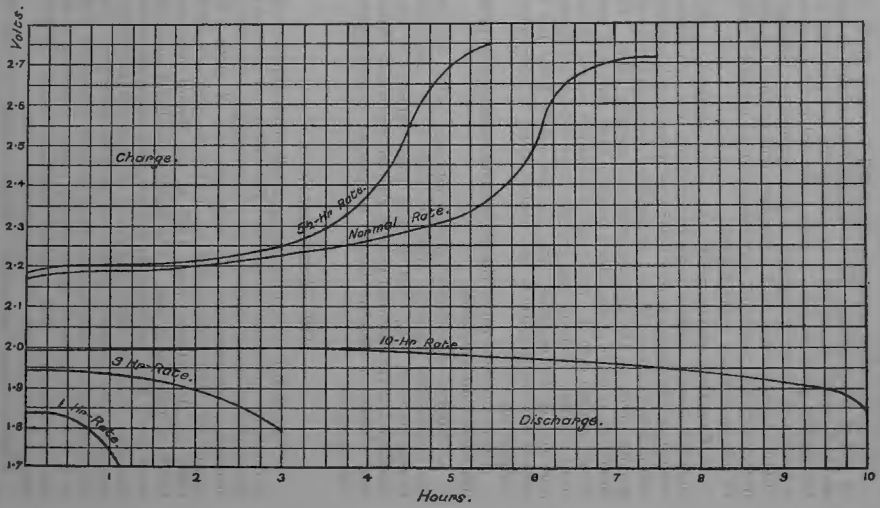
110. *Electro-motive force.*

1. The E.M.F. of a fully charged cell, on commencement of discharge, averages about 2V. The voltage at the end of the discharge varies with the rate, decreasing as the rate of discharge increases, and also with the size of plate. The figures for plates under 400 sq. inches in area are about 1·85V at the 10-hour rate, 1·8V at the 3-hour rate, and 1·75V at the 1-hour rate. The further discharge of a cell when the E.M.F. has fallen to this specified minimum is very injurious, owing to the formation of an insoluble sulphate on the plates, the effects of which will be dealt with later. For this reason, a cell must be considered as fully discharged when its E.M.F. has fallen to the minimum value, according to the rate of discharge. The moment discharge ceases the volts should rise to between 1·98 and 2 on open circuit.

During charge, the applied voltage necessary to maintain the normal charging current depends on the E.M.F. of the

PLATE 124.

VOLTAGE CURVES, CHARGE AND DISCHARGE.



cell and its internal resistance. This voltage will be about 2·15**V** at the start of the charge, rising slowly to 2·3**V** and then more rapidly to between 2·55**V** and 2·75**V**. The electrolyte now has the appearance of boiling, an effect which is known as *gassing*.

On discharge at normal rate the E.M.F. falls rapidly to 2**V**, or just below, where it remains constant for a considerable time, finally falling to the values given above at the end of discharge.

Pl. **124** shows the variation of E.M.F. of a typical cell during charge and discharge.

111. *Capacity and efficiency.*

1. By the **capacity** of a cell is meant the number of ampere-hours which it is capable of supplying under certain definite conditions. This capacity varies a good deal for any given cell, and depends not only on the rate of discharge, falling rapidly with a heavy discharge current, but also on the temperature, age, and condition of the cell.

Thus, when a cell is said to have a capacity of 400**Ah**, it means that, when it is discharged at a certain definite rate in amperes, the temperature being 60° F., until such time that the E.M.F. has fallen to a predetermined minimum value (generally 1·85**V**), the product of the current in amperes and the time in hours will be 400.

2. The **nominal capacity** is generally calculated on the 10-hour rate, though 9-hour and 8-hour rates are sometimes met with, so that, to come up to its rating, a 400**Ah** cell must not have dropped below the predetermined minimum voltage after 10 hours of discharge at 40**A**.

If the discharge current is increased, the time taken for the cell to be completely discharged will not be decreased proportionally but will diminish at a greater rate as the current increases. For example, the capacity at the 3-hour rate is approximately 71 per cent. of that at the 10-hour rate. Pl. **125** shows the capacity of a typical cell at different rates, expressed as a percentage of that at the 10-hour rate.

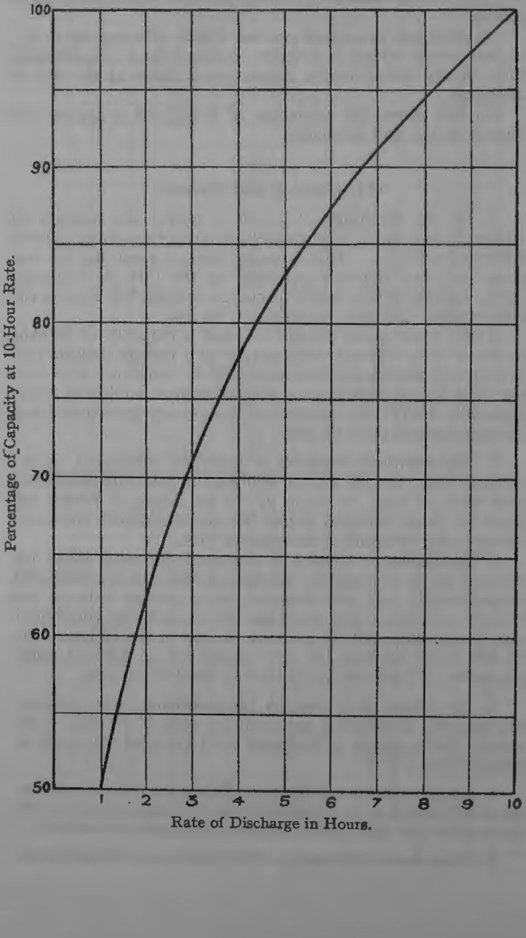
3. The **effect of a rise in temperature** is to increase the capacity by about 1 per cent. for each 2° F. rise. Conversely, the capacity is decreased by 1 per cent. by a fall in temperature of 2° F.

4. **Ampere-hour efficiency.**—This is the ratio of ampere-hours of discharge to ampere-hours of charge, and may be taken as 90 per cent. under ordinary conditions of working.

5. **Watt-hour efficiency.**—This is the ratio of watt-hours

PLATE 125.

CAPACITY AT DIFFERENT RATES OF DISCHARGE.



of discharge to watt-hours of charge. If watt-hour meters are not available, the value will be given approximately by

$$\frac{\text{Average volts during discharge}}{\text{Average volts during charge}} \times \text{Ampere-hour efficiency.}$$

This will vary according to the rate of discharge and should be not less than 75 per cent. at the 10-hour rate.

112. *Erection of batteries.*

1. **General arrangement.**—Cells are almost invariably mounted in rows on racks or stands. These rows should preferably be single and in one tier. If the available floor space does not admit of this arrangement, either two rows may be placed side by side, or the rows may be in two or three tiers, one above the other. In the latter case, sufficient headroom must be left to allow the plates of cells in the lower tiers to be easily removed without disturbing the cells. Fixing the racks all round the walls of the room is not recommended, as this arrangement increases the difficulty of proper inspection. In almost every case, the cells which are least accessible are the first to give trouble.

2. **Stands.**—Pitch-pine stands, fastened without using metal, are usually employed. These should be coated with black tar varnish. Another form of stand consists of pitch-pine rails on glazed brick pillars.

3. **Insulators.**—Owing to the spray which is given off by a fully charged cell, the containing box is always more or less covered with a film of acid moisture. It is imperative, therefore, to insulate each cell from its stand. This is done by standing the containers on glass or porcelain insulators of the form shown on Pl. **126**, Fig. 1, four insulators per cell being generally used. A small quantity of non-drying insulating fluid, such as resin oil, is placed in the lower half of the insulator.

4. **Trays.**—If glass containers are provided for cells of moderately large capacity (400**Ah** and above), they should stand in shallow pine or hard wood trays, instead of being placed directly on the insulators. The trays should be kept filled with loose dry sawdust, which serves to distribute the weight of the cell evenly over the glass bottom, and should be given two coats of anti-sulphuric varnish.

This used to be the standard practice for all glass cells, but there is no necessity for the trays with the smaller sizes of cell. With these the glass containers may be set directly on the insulators, as are the lead-lined wooden boxes, but discs of rubber or soft lead should be inserted between container and insulator.

PLATE 126.

SECONDARY CELLS.

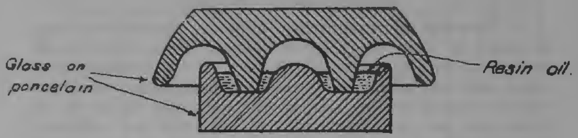


Fig. 1. Insulator for supporting tray or box.

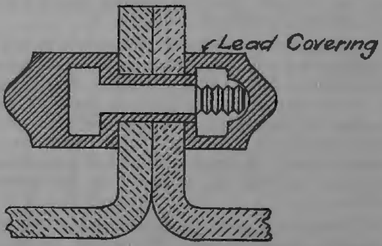


Fig. 2. Bolted connection.

5. **Connections.**—Cells are connected in battery either by burning or bolting together the straps or lugs of the connecting bars (*see* Sec. **108**, para. 2). The former is the better connection, but is likely to lead to the neglect of individual cells, since it is a matter of some time and skill to disconnect and connect up again cells which require treatment. Cells connected by bolts are very readily disconnected and, if necessary, removed, but the connections require careful watching ; it is very easy to get bad contacts or even a total disconnection when the nuts are apparently quite tight. Bolts must be of acid-resisting metal ; pure lead is too soft, and lead-antimony, although considerably harder, is brittle and the thread is apt to be stripped when nutting up tight. A non-corrosive type of bolt and nut is now used which has all parts coated with lead, the core being of iron or brass. The present War Department Specification states that all connections shall be bolted. Pl. **126**, Fig. 2, shows a typical bolted connection.

Other connections may be of bare copper suspended from the ceiling with porcelain insulators, and painted with several coats of paint ; or lead covered, or alternatively T.R.S. cables.

6. **Erection by contract.** — Normally all batteries installed for the War Department at home stations are erected by contract, the station finding unskilled labour for assisting in handling the material during the unpacking and erection of the cells. All building work, wiring of lights, &c., should, if possible, be finally completed before the battery is installed.

The initial charge and also the capacity and efficiency tests are supervised by the contractor, but are officially carried out by a representative of the C.I.R.E.S., Woolwich, who, on completion of the tests and inspection, hands the battery over to the responsible local officer.

7. **Erection by station personnel.**—When batteries are not erected by contract, *e.g.*, at foreign stations, the following procedure should be followed :—

i. The stands should be erected in the positions in which the cells are to be fixed, care being taken to allow ample space for the cells to be inspected from both sides or removed, if so desired, without disturbing other cells.

ii. The glass insulators should then be unpacked, thoroughly cleaned and dried, and a small quantity of resin oil placed in the bottom halves, any excess being carefully wiped off. They should then be placed in position on the stands.

iii. Where wooden trays are employed, they should next be removed from their cases, thoroughly cleaned, well filled with clean dry sawdust, and placed on their respective insulators. They should be levelled by the use of thin lead discs, which are supplied for this purpose, and accurately spaced in accordance with the battery plan supplied.

iv. The glass or wooden boxes should now be unpacked and thoroughly cleaned, particular attention being paid to the cleaning of the insides of the glass boxes. If the latter is not attended to a thin film of dirt may form on them, and when the electrolyte is put into the cells accurate inspection will be difficult. The boxes should be set on their respective insulators or trays and adjusted for uprightness and spacing.

v. The plates for the first cell should now be unpacked. To do this, first remove the tops and sides of the cases, which are usually secured with wooden screws, and then remove the packing pieces and securing blocks. The positive and negative groups should then be carefully slid out of the side of the box or lifted by means of the canvas band with which they are secured, care being taken to keep the plates vertical. *Groups should on no account be lifted by their connecting bars.* As they are unpacked, the plates should be carefully examined and any defects, such as the lower corners of the plates being bent up or the lugs bent out of shape, should be remedied by the use of a pair of flat tongs. All dirt having been brushed from the plates, they should be placed in a rough, locally-made frame, which will hold them in a vertical position. The positive and negative groups having being placed in this frame and trued up, the separators should be placed in position and the whole firmly secured with the canvas bands which were fastened round the plates when packed. The plates are then ready to be placed in the containing box. They should be evenly lifted by means of wooden lifting bars, passed under the ends of the lugs, and lowered into the box; the lifting bars should then be carefully removed, the ends of the lugs being allowed to rest on the edges of the box in the case of glass boxes, or on the glass hangers, which should previously have been inserted in the box, in the case of wooden boxes. The canvas securing band should then be removed, the plates trued up, and the separators adjusted.

vi. The plates having been placed in the second cell in a similar manner, the connecting straps should be prepared for bolting up, being carefully and gradually set up to the required shape. Some makers now shape the ends of the connecting bars into lugs, which obviates the necessity for bending up the straps, but it may be found necessary to set some of the lugs slightly. The straps or lugs and the bolts having being thoroughly cleaned, the joints should be made in the following manner.

Dry the joint and warm the bolt with a spirit lamp. Insert the bolt when warm into the bolt-hole and tighten up the nut as much as possible, using the special spanners supplied with the battery. Care should be taken not to touch the joint with the hand. When completed, the outside of the joint should be warmed and given a thick coat of anti-sulphuric enamel or black tar varnish.

vii. The procedure detailed in sub-paras. (v) and (vi) should now be repeated with each cell until the erection of the battery is completed.

113. *Initial charge.*

1. The first charge of a battery is the most critical point of its history, and every care should be taken to conform to the maker's instructions. It has not yet proved practicable to supply a battery of over 200 ampere-hour capacity in a fully-charged state; hence the plates are delivered in a formed state, *i.e.*, they have been treated until they are capable of retaining a charge, but lack the actual charge which will enable them to yield their rated output. As soon as the electrolyte is poured into the cells, preparatory to putting the battery into commission, the acid begins to combine with the plates to make lead sulphate. The object and effect of the first charge is to soften the plates and convert the lead sulphate into healthy active material. The fact that the acid has commenced to combine as mentioned can be perceived by a change in the colour of the plates, but especially by the gradual lowering of the specific gravity for several hours, even if the battery is put on charge immediately. The action set up by the charging current, if continued long enough, gradually desulphates the plates and drives the acid back into the electrolyte. The initial charge can only be considered complete when this has been done thoroughly and effectively.

Short first-charge plates.—The sulphating process referred to affects the negative plates far more than the positive, owing to the fact that they become oxidized through the action of the atmosphere in the interval between manufacture and erection.

Batteries in which the first charge can be completed in 15 to 20 hours are now on the market. The negative plates are dried in inert gases during the process of manufacture immediately after reduction, and if the plates are kept bone dry no oxidation will take place.

2. **Filling with electrolyte.**—On completion of erection, as described in Sec. **112**, and having made sure that everything, **including the engine,** is ready for charging, the cells should be filled as rapidly as possible with electrolyte of the correct specific gravity. *There should be no break in the continuity of filling the cells* and enough acid should be put in to ensure that the plates will be covered at the end of the charge. The polarities of battery and generator should then be checked and the final connections made at the end of the battery.

3. **First charge.**—This should commence *immediately* after filling with electrolyte and should be carried out in accordance with the instructions given by the makers. It should be continuous for at least 24 hours for ordinary plates and 8 hours for short first-charge plates, and will be complete when the electrolyte in all the cells has attained its maximum permanent specific gravity. It is not sufficient merely to charge until the specific gravity has apparently ceased to rise, but the charge should be continued for some 8 hours after this point, until it is assured that this maximum is constant. In short first-charge batteries two hours of this further charging usually suffices.

4. **Specific gravity check.**—When the electrolyte of the whole battery has reached its maximum density, if the specific gravity of any cells is different from the value given in the maintenance table, it should be adjusted to the correct value by adding distilled water or dilute acid.

5. **Appearance at end of first charge.**—When the battery has received its first or initial charge on site, the plates are in a fully charged condition and ready to be put into active service. The plates should all have a thoroughly healthy colour—positives, a rich chocolate, negatives, a light slate hue—but they will feel more or less harsh and metallic. The smooth feel of a healthy plate will not mature until the battery has been at work some little time. The plates should all hang vertically and equi-distantly from one another. The acid should be colourless and free from smell ; the level of the acid should be identical in each cell, and the specific gravity of the acid in any cell should not differ by more than 0·002

from the average of the whole battery. The connections should be re-made thoroughly tight after charge, and be covered with a coating of black tar varnish or anti-sulphuric enamel.

6. **Procedure immediately following first charge.**—If, after charging the battery for the first time, it is left idle for several days, the plates will assume a sickly appearance, the positives turning light brown, yellow, or even white, and the negatives turning white, either completely or in patches. This is the result of the acid combining with the active material and forming lead sulphate. Before taking the battery into general use a capacity test should be made.

The correct treatment of a new battery is to give it plenty of work, of an artificial nature if necessary, taking care not to make the periods between charges too protracted, and giving an extra hour's charge on the first six occasions. The battery may then be considered to be in a stable condition, and several years of smooth running are assured, provided that it is properly looked after and not misused.

When the battery has reached this stable condition, the specific gravity of the electrolyte should be adjusted, if necessary, cell by cell, to agree with the value given in the maintenance table, by adding either distilled water or diluted acid of not more than 1·4 specific gravity.

114. *Working procedure and voltage regulation.*

1. **General treatment.**—The most important point in connection with the maintenance of a battery is that all the cells should receive regular work. Any ill-treatment, specific cases of which are detailed in para. 10, or irregular work will not only result in loss of capacity and reduced efficiency but will also shorten the life of the battery. It must also be remembered that a secondary cell is merely a reservoir of energy, not a producer, and that it is courting disaster to attempt to work it like a generator. The full capacity cannot be expected on a discharge unless it has been preceded by a full charge. A full charge, moreover, means one by which every cell in the battery has been brought to the fully-charged state. If, owing to neglect, certain cells have been allowed to get into a lower condition than the remainder, they will not reach a fully-charged state with the latter and will consequently not be equal to the work on discharge. If the discharge is continued beyond the point at which they drop out of action they may be permanently injured. For this reason any cells which show signs of not being up to full capacity must be cut out of circuit towards the end of discharge and specially treated. A milking booster, *e.g.*, a portable motor

generator with a low voltage generator, is useful for this purpose.

If the battery is liable to be called upon to deliver at any moment any current or output within its ratings it must be kept in an absolutely fit condition, so that all its cells reach the fully-charged state more or less simultaneously.

2. **Charging.**—When a cell is gassing most of the energy put into it is wasted, with a consequent low working efficiency. Gassing charges should therefore not be given more often than necessary.

The best routine procedure is to give the battery an " ordinary " charge whenever it becomes discharged with a gassing charge at intervals of not more than a fortnight. If a daily charge is given a gassing charge once a week is desirable. The normal charging current is specified by the makers and is generally not greater than the current which would be given by the battery when discharging at the 7-hour rate. A maximum charge rate is also specified, and this may be used at the beginning of charge when essential, but once the cells have started to gas the current should be reduced to a value of one-tenth or less of the ampere-hour capacity of the battery.

Ordinary charge.—There are two methods of determining the correct moment to stop charging :—

(*a*) Charge till the S.G. of the lowest cell is 5 points below that obtained on the last gassing charge.

(*b*) If the average ampere-hour efficiency is x per cent., and the discharge since the last charge is y ampere-hours, put in $y \times \frac{100}{x}$ ampere-hours. This method is recommended.

Gassing charge.—These charges must be continued until :—

(*a*) All the cells are gassing and all the plates are healthy.

(*b*) Voltage and specific gravity are constant and at their correct maximum values.

It is, of course, impossible to get a true reading of the S.G. while gassing continues ; common practice is to record the S.G. after the charge has stopped and gassing subsided.

Charging can be carried out by means of a shunt-wound generator of suitable voltage ; but, where a battery is charged from bus-bars, which have to be kept at a constant voltage approximating to that of the battery on discharge, it will be necessary either to charge it in sections or to employ a small auxiliary generator between the bus-bars and the battery. Such a machine is known as a *booster* and is provided with an adjustable resistance in circuit with its field winding, whereby the voltage may be varied from a very small value to the maximum required. The booster is motor-driven, and is wound for the full charging current and for a maximum voltage corresponding to the increase between the normal discharge voltage of the battery, *i.e.*, about 2V per cell, and the full voltage of the battery at the end of charge, *i.e.*, about 2·75V per cell.

In the Service, it will often be necessary to use a compound-wound generator for charging. In this case the series coil may be cut out, thereby converting the machine into a shunt-wound one. Provided, however, that there is an automatic cut-out in circuit with the battery, there is no reason why a compound-wound machine should not be used.

Pl. 33 shows diagrammatically how a battery and booster are connected to station bus-bars.

3. **Trickle charge.**—It has been previously explained that to maintain a battery in good condition work is essential, and that the plates of a battery standing idle or doing very little work will be attacked by the electrolyte and deteriorate. Batteries used for stand-by purposes in power stations or searchlight emplacements, or in telephone exchanges, never get a proper discharge, but must be ready at any moment to give their full capacity. It is found possible to maintain an idle battery in good condition by a steady trickle charge just sufficient to counteract the sulphating action of the electrolyte. The amount of this charge is about 2 per cent. of the 10-hour capacity spread over the 24 hours ; *e.g.*, for a 600 ampere-hour battery it would be $\frac{2 \times 600}{100 \times 24} = \frac{1}{2}$ ampere. To this must be added the amount of any very light duty the battery has to perform.

If the battery at any time has a proper discharge it must be recharged fully by the usual methods before it is left to trickle charging.

4. **Discharge.**—A battery can stand a very high rate of discharge provided that it is not continued beyond the time shown on the battery discharge curves. The voltage of a cell does not fall uniformly or regularly as the discharge continues, and cannot be used as an indication of the capacity left in the battery at any moment. The specific gravity, however, does fall uniformly, and if the working range of the acid is found when a battery is installed, a straight-line chart can be constructed to show what residual capacity corresponds to any S.G. For instance, if the working range of a certain 800 ampere-hour battery is found to be from 1,215 to 1,155, or 60 points, and on test the S.G. is found to be 1,170,

the battery is ¾ exhausted, and not more than 200 ampere-hours can be taken out at the 10-hour rate without a recharge.

No discharge should be continued below the voltages given in Sec. **110**, para. 1, and great care must be exercised when discharging at high rates to avoid ruining the battery, as the voltage falls very rapidly when the cells are nearly exhausted.

Voltage regulation.—Fig. 100 is a diagram of connections of a battery charge and discharge circuit in its simplest form. Owing to the higher voltage of the cells at the beginning of the discharge, fewer cells are required at first than later on, and therefore additional cells, known as "*end-cells,*" have to be switched on as the discharge proceeds. For this purpose a regulating switch must be provided on the discharge side of the battery.

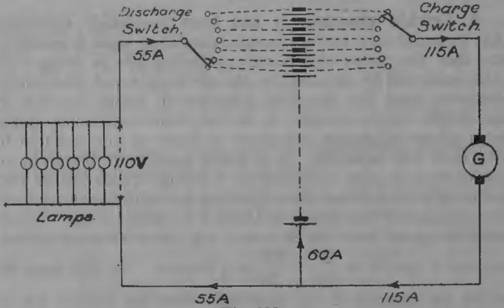


Fig. 100.

As these end-cells are not discharged to the same extent as those in the main part of the battery, they will naturally be charged more quickly, and it is necessary therefore to have a regulating switch in the charging circuit as well.

When the contact arm of either of these switches passes from one stop to another it must not break the circuit or short circuit the cells. These requirements are met by using a pilot arm connected through a resistance to the main arm. Thus, before the main arm has left one stud the pilot arm has made contact with the next. For relatively small currents, regulator switches are usually made circular—the contact studs being arranged in a circle round a central point about which the contact arm turns. An interlocking device is frequently provided which prevents more cells being included in the discharge circuit than in the charge circuit. For larger sizes, the contact studs are usually arranged in a straight line, the moveable contact being operated by a screw or rack.

In the following consideration it will be assumed that the cell voltage is 1·85 at the end of discharge and 2·7 at the end of charge, and that the bus-bar voltage is 230.

$$\textit{Number of cells required} = \frac{230}{1{\cdot}85} = 125.$$

At the beginning of the discharge $\frac{230}{2} = 115$ cells only are required, therefore, from a discharge point of view, 10 end-cells are necessary.

Now the total voltage required to charge the battery $= 125 \times 2{\cdot}7 = 337{\cdot}5$V, and as the supply has usually to be maintained while the battery is being charged, the *load* voltage must be kept at 230 throughout, and the generating plant must provide for an increase of $337{\cdot}5 - 230 = 107{\cdot}5$V for charging purposes.

In practice such a large increase is never required, since during the greater part of the discharge, $\frac{230}{2} = 115$ cells only are required, and as the other 10 cells are discharged less than the main part of the battery, they will come up on charge much more quickly and can be cut out of the charging circuit before the voltage of the cells in the main part of the battery exceeds (say) 2·3 or 2·4. Allowing for this, the extra voltage required to charge the battery is reduced from 107·5 to $107{\cdot}5 - 27 = 80{\cdot}5$V.

The requirement may be met either by

i. *A Special Charging Generator and a relatively large number of end cells*, or
ii. *A Charging Booster.*

i. *Special charging generator and end cells.*—If the generator is designed to give a voltage range of 230/320V it is possible to satisfy the conditions, but towards the end of the charge the discharge switch (Fig. 100) must connect the load to $\frac{230}{2{\cdot}7} = 85$ cells only, and therefore there must be no less than 40 end cells. This is the main reason why this method of charging is only employed in quite small low-voltage installations. It will be evident that these end cells work under the worst possible conditions, and special attention must be paid to their care and maintenance.

In practice, for a bus-bar voltage of 230, it is usual to install 126 cells with 40 end cells connected to the regulating switch in pairs.

It will be clear from Fig. 100 that when the generator is charging the battery, the end cells included between the contact arms of the two regulator switches get the full charging current while the main body of the cells only get an amount equal to the difference between the full generator current and the current in the supply mains. Unless a good deal of care is exercised this arrangement leads to the over-charging of the end cells.

They should always be put on at the beginning of the charge period and cut out immediately they become charged, and they should be changed round periodically with some of the other cells if they cannot be kept in good condition in ordinary use.

ii. *Charging booster.*—This is much the better method since the number of end cells required is determined by discharge considerations only. Connections are shown in Pl. **33.**

A simple charging booster set comprises a shunt generator coupled to a motor, the latter being supplied from the 230V bus-bars. The booster is designed to give a voltage from 0 to (say) 80 volts at the normal battery charging current.

Automatic reversible booster.—End cells may be dispensed with altogether if the booster is made reversible so that it assists the battery when discharging.

Various types of automatic reversible booster are available for keeping a battery " floating " on the bus-bars, discharging during periods of heavy load and charging when the load is light, thus keeping a constant load on the generating plant at all times. For details of these arrangements reference must be made to standard textbooks.

115. *Maintenance.*

1. **Topping up.**—The electrolyte in the cells should be half an inch above the tops of the plates, and maintained at this level by adding a sufficient quantity of distilled water just before commencing to charge, when the specific gravity is lowest. The water should be forced in at the bottom of the cell by means of a syringe, so that it may mix thoroughly with the electrolyte.

It must be remembered that the presence of gas bubbles in the electrolyte increases its volume. The electrolyte may be well over the plate tops while the cells are gassing and yet fall below them after the charge has stopped.

2. **Spare container.**—A spare container, filled with electrolyte, into which the plates of a cell can be placed in the case of a container breaking, should be kept ready in the battery room. This will protect and preserve the plates while the necessary repairs are effected.

3. **Idle battery.**—A battery should never be left in a discharged state, but should be fully re-charged as soon as possible after discharge. If it is to be idle for a few weeks, it should be fully re-charged as usual, and the charge con-

tinued for about one hour at half the normal charging rate with the cells gassing. During the idle period it should be given a charge once a fortnight at approximately half the normal charging rate for about 1½ hours. When brought into regular use again it may not give its full capacity on the first few discharges, but this defect will disappear after three or four reasonable discharges.

If the period of idleness is likely to be prolonged to months, it is better to take the battery out of commission, as described in Sec. **118.**

4. **Inspection.**—A battery should be thoroughly inspected at least weekly, each individual cell being carefully examined. Specific gravity and voltage with normal discharge current flowing should be noted, and the plates should be thoroughly examined for any signs of buckling, excessive sulphating, or other indications that they are not in a healthy state. The connections should be felt with the hand during charge to detect any excessive heating, which indicates a faulty connection.

A general inspection should also be made daily.

5. **Records.**—These, if carefully kept, serve a very useful purpose. The following should be recorded weekly :—

i. Voltage of each cell—
  (*a*) at end of discharge, if possible with normal current flowing,
  (*b*) at end of charge, if possible with normal current flowing.
ii. Specific gravity of each cell—
  (*a*) at end of discharge,
  (*b*) just after cessation of charge.
iii. Temperatures of a few cells at the time the voltages and specific gravities are taken.
iv. Temperature of battery room, at same time as (iii).
v. General condition of battery.
vi. Any particular treatment given to individual cells.
vii. Date of topping up cells.

Accurate records of the output and input of the cells should also be kept, showing rate, duration, and date of all charges and discharges.

The readings should be taken with accurate instruments, and should preferably be recorded in a Battery Log Book (Army Book 309).

6. **Common mistakes in management.**—The mistakes which are commonly made, either through ignorance or carelessness, in the management of batteries, together with the resultant effects on the plates, &c., are given below. Such

errors in management should always be detected before they cause undue harm, if proper records are kept and the weekly inspection of the battery is efficiently carried out.

i. *Too little charging.*—Negatives blotchy or white and active material hard. Positives light in colour, harsh in feel, and badly sulphated. Light coloured, even white, sediment, consisting largely of sulphate. Low specific gravity.

ii. *Too much charging.*—Heavy accumulation of spongy lead on top edges of negatives. Positives darkened in colour almost to black. Heavy deposit of sediment, mainly chocolate-coloured positive material.

iii. *Working battery too little.*—Negatives blotchy or white and active material feeling gritty when squeezed. Positive active material hard and metallic. Specific gravity irregular and low.

iv. *Running battery too low.*—Grids of negatives darkened, active material expanded and causing gauze to bulge. Positives considerably sulphated and scaling. Dull grey sediment under negatives.

v. *Charging at too high a rate.*—Negative material exuding through gauze. Positives appear scrubbed and deficient of peroxide, and probably buckled. Sediment of coarse positive active material and negative material under respective plates.

vi. *Charging at too low a rate.*—The plates would become sulphated, the amount of sulphate depending upon the number of low-rate charges. There would, however, be no harmful effect, unless the charging rate was less than one-third of the normal rate.

vii. *Internal short-circuit.*—Low voltage. If allowed to continue, positives may turn brick-red, wholly or in patches, and negatives may become discoloured.

viii. *Failure to top-up cells and allowing tops of plates to become exposed to the air.*—Remainder of plates will show indications of overcharge.

ix. *Allowing bolted connections to become dirty or slack.*—Connections warm.

x. *Failing to attend to weak cells properly.*

7. Portable batteries.—Portable batteries differ from stationary ones in matters of detail only, but they are usually handled by unskilled personnel, have to suffer hard usage, and facilities for adequate testing and treatment are as a rule not available. Again, the specific gravity of the electrolyte is high, perhaps as high as 1,300 when the battery is fully charged in order to obtain maximum capacity for a given size and weight. As a result of these factors the life to be expected from a portable battery is low. Two or three years ago a life of 50 complete cycles for a 20-amp.-hour battery was normal; batteries now being made are, however, considerably improved, and should last for 150 cycles before their capacity falls below 90 per cent. of their original value.

Portable batteries are usually fitted with a non-spill device. Care must be taken not to put in too much electrolyte, as if the battery is filled above the correct level, this device will not function.

High tension batteries for wireless work, with very small cells and output, need special apparatus for re-charging, and may easily be ruined if this is done injudiciously. It is, however, only necessary once every three months or so.

Car starting batteries have unusually severe conditions to contend with. They are generally of about 50 to 80 ampere-hours capacity, and when starting the car have to supply a current of 120 amperes or more. If the engine is sluggish, or in a bad condition, this demand may continue sufficiently long to damage the battery.

Overcharging in the summer is another evil to be guarded against.

Again, if a vehicle is used for short journeys exclusively, involving frequent use of the starter, the battery will never get properly charged. It will, in such circumstances, be very desirable to remove the battery every two or three months and give it an extended charge.

Storage of small lead batteries is a matter of considerable difficulty, as the plates cannot be dried without some method of pumping hot air over them. Batteries kept in store should therefore be kept fully charged, a refresher charge being given about once a month.

116. *Diseases and their remedies.*

1. **Sulphating.**—Although the normal action of a battery depends on the conversion of the active material to lead sulphate at every discharge, improper treatment will lead to excess formation of crystals of various lead sulphates, which ordinary charging will not remove. Such abnormal sulphation on the plates, besides indirectly causing various defects, is directly injurious by interposing a non-conducting layer between the active material and the electrolyte, *i.e.*, part at least of the active material is inoperative and the capacity of the cell is thereby reduced. The effect is cumulative and, unless steps are taken to remove the sulphate, the plates will soon be ruined.

Sulphating may be due to :—

i. Discharging at too high rates.
ii. Allowing cells to stand idle, particularly when discharged.
iii. Insufficient charging.
iv. Local action, caused by impurities in the active material or electrolyte, resulting in over-discharge of portions of the active material.
v. Loosening of the active material by over-charging. Portions of the active material then are not traversed by the current on charge, and consequently become over-discharged.

The disease manifests itself as a growth on the plates, generally a white deposit on the negatives and a reddish scale on the positives.

The remedy is prolonged charging at low rates, about half the normal. If the plates are not very badly sulphated, the charge may with advantage be given as follows :—

Start at half-normal rate. After one hour increase to normal rate, and after another hour to maximum rate. The maximum rate should be maintained for not more than one hour; the rate should then be reduced to normal and so remain until the cells are gassing, when it should again be reduced to half-normal or less. After this charge, discharge the cells at normal rate and repeat the charge as above, the process being continued until the plates are in a thoroughly healthy condition.

Sulphated plates may also be subjected to an alkaline treatment as follows :—

Draw off the electrolyte and thoroughly clean the plates in pure water. Pour in a solution of from 2 to 5 per cent. by weight of caustic soda, and then put the cell on charge at the normal rate. If at any time during the charge the solution gives an acid reaction, add caustic soda until a positive alkaline reaction is obtained. The charge should be continued until the plates have a healthy appearance. Draw off the caustic solution and replace the electrolyte. The cell should finally be given a gassing charge.

Repetitions of over-discharging, &c. may lead to the formation of an irreducible variety of sulphate which no amount of over-charge will effect. In such an event, it may be necessary to scrape the scale off before proceeding to give the special treatment detailed above. In extreme cases, replacement of the plates may be the only remedy.

2. **Buckling.**—Buckling of the plates is another manifestation of excessive sulphating, and is generally caused by charging or discharging at too high rates. Positive plates

are most affected, owing to the alteration in the bulk. The material swells probably more on one side than the other, and distorts the framework of the plates.

It may be arrested in its early stages by shifting the separators between the plates. If more pronounced, strips of specially treated wood should be inserted between the plates to prevent short-circuits. Attempts to straighten buckled plates should not be made, as they would probably lead to cracking the plates or dislodging the active material, and would do more harm than good.

Prolonged charging at low rates may soften Planté positive plates sufficiently to enable them to be straightened in a hand-screw press.

3. **Short-circuiting between plates.**—Buckling, if very pronounced, may actually cause the plates to touch ; short-circuits may also occur through the falling off of particles of the active material and consequent bridging between plates. This trouble may be accentuated by blistering, especially in the case of negative plates, where over-charging causes spongy lead to grow out and lessen the space between the negative and adjacent positives. Sediment at the bottom of the cell, if allowed to accumulate indefinitely, will in time reach the level of the plates and so cause short-circuits.

Flakes of active material which have fallen away and become lodged between the plates can usually be removed by a thin strip of ebonite. Sediment should be removed when it reaches a dangerous level by syphoning off the electrolyte and washing out the cell.

4. **Backward cells.**—Should a cell refuse to gas with the others on charge, it should at once be examined for short-circuits or other faults and cut out of the battery during discharge. This may be done by disconnecting it from one of the adjacent cells and bridging the gap by means of a short piece of cable with a brass clamp at each end, which should be kept for such a purpose in the battery room. Reinsert the faulty cell on the next charge ; after a few such charges, without discharges, the cell will probably have recovered.

5. **Cadmium tests.**—If a cell becomes seriously defective, and it is necessary to determine whether it is the positives or the negatives that are at fault, a cadmium test should be applied.

In this test, a small pencil of cadmium is attached to the negative lead of a cell-testing voltmeter and is dipped into electrolyte as near the middle of the cell as possible, care being taken that it does not come in contact with either the plates or the connections. The other voltmeter lead is then connected to the positive or negative terminal of the cell, according to which element it is desired to test.

After the cadmium has rested in the cell for a few minutes, the following results should be obtained :—

At end of charge with normal charging current flowing—

P.D.	$+^{ve}$ plate to cadmium	+2·5 volts
	$-^{ve}$ plate to cadmium	−0·2 volts
	Giving a cell P.D.	2·7 volts

At end of a 10-*hour discharge with discharge current flowing—*

P.D.	$+^{ve}$ plate to cadmium	+2·05 volts
	$-^{ve}$ plate to cadmium	+0·2 volts
	Giving a cell P.D.	1·85 volts

These exact values will not be given by every cell, however healthy, in practice, as they depend on too many variables, but the following remarks are applicable, whatever the exact values may be.

It will be seen that as the charge proceeds, the potential of the negative plate to the cadmium should reverse, and it will do this when about four-fifths of the charge is completed. If it is found not to have reversed it is a sure sign that the plates are not fully charged.

If at the end of discharge the potential of the positives is less than 2 volts above that of the cadmium, the active material is exhausted. Similarly, if the potential of the negatives is more than 0·2 volts above that of the cadmium it is the negatives that are exhausted.

It must be again emphasized that the figures given only apply to 10-hour rates of discharge. With higher rates, higher values of these potentials are normal and to be expected.

117. *Taking over a storage battery.*

1. An officer or mechanist taking charge of a storage battery, whether on arrival at a new station or when the battery is first erected, should take steps to assure himself that it is in a healthy condition and up to its work. The following procedure is recommended :—

- i. *Inspection of record book.*—Records are often carefully kept and seldom looked at. They are, however, a valuable guide to the state of the battery and plates.
- ii. *Visual inspection.*—The correct appearance and feel of the plates is described in Sec. **107.** Bad colour may be due to impurities in the electrolyte, to sulphation, or to sluggishness as a result of insufficient work. Sluggish plates will show a healthy colour underneath if the surface is rubbed hard.

The electrolyte should be clear and colourless; brown discoloration is a sign that the battery has been overcharged at too high a rate. The deposit should not be excessive in quantity, should be a deep brown and soft. A light coloured deposit is a sign that the battery has had too little work. Buckled positive plates do not affect the battery capacity as long as they do not cause short-circuits.

iii. *Capacity and efficiency tests.*—There is no authoritative standard for these tests, which are difficult to carry out with accuracy owing to the indeterminate effects of temperature and other factors, and the difficulty of ensuring that the battery is in the same chemical state at the end of the test cycle as at the beginning.

The following procedure is given in D.W. Standard Specification No. 16—Secondary Batteries, lead acid type—as that to be employed for acceptance tests :—

Clause 25. **Capacity.**—i. The battery shall be capable of giving a discharge for the purpose of test, at the 5-hour rate, not less than 83 per cent. of the capacity offered at the 10-hour rate. The capacity at the 3-hour rate shall be not less than 72 per cent. of that offered at the 10-hour rate, subject to the proviso contained in Clause 27.

ii. (*a*) After completion of the first charge, the battery shall stand idle for a period of not less than 12, and not more than 18 hours and will then be discharged at the 5-hour rate, *i.e.*, 1·66 times the 10-hour rate offered (to prove the capacity of the battery) to an average voltage of 1·82 volts per cell, or until any cell falls below 1·8 volts, whichever occurs first. The capacity so found shall not be less than 83 per cent. of the capacity offered at the 10-hour rate. Before discharge the specific gravity of any cell shall not exceed 1·215, and during discharge the specific gravity shall not fall below 1·160.

(*b*) *Watt-hour input.*—Having discharged the battery for capacity, the battery will be re-charged. The input in ampere-hours shall be the amount, corrected to 60° F., taken out during the previous discharge, plus 10 per cent., and must be put in in 5½ hours. The battery will then stand idle for a period of not less than 12 hours, and not more than 18 hours. During this interval the battery will be disconnected from its terminals at the switchboard and will not be disturbed in any way.

(*c*) *Watt-hour output.*—After the expiration of the time stated in (*b*), the battery shall be again discharged as detailed in (*a*).

A correction for capacity in each case on the average temperature of electrolyte during the whole discharge will be made, calculated at 1 per cent. per 2° F., and shall be subtracted above 60° F., and added below 60° F., to the capacity obtained, whether this correction is the true coefficient for the battery or not.

Clause 26. **Watt-hour efficiency.** — On the charge described in Clause 25 (ii) (*b*), and the discharge actually obtained at the 5-hour rate, *vide* Clause 25 (ii) (*c*), the watt-hour efficiency will be computed, and shall not be less than 72 per cent.

Clause 27. **3-hour rate.**—The 3-hour rate of discharge shall be 2·4 times the 10-hour rate offered. On the completion of the watt-hour efficiency test, the battery will be again charged as above, and will again stand idle as described in Clause 25 (*b*).

After the expiration of the time therein mentioned, the battery will be discharged at the 3-hour rate, and must be capable of giving a capacity not less than 72 per cent. of that offered at the 10-hour rate, the final voltage during discharge being not less than an average of 1·8 volts per cell, and no cell shall have a voltage of less than 1·78 volts. Preference will, however, be given to batteries whose capacity at their true 3-hour rate is not less than 85 per cent. of their capacity at the true 5-hour rate, although this is not a condition of acceptance test.

iv. *Cadmium test.*—The plates of any suspected cell should be tested as described in Sec. **116**, para. 5.

118. *Taking a battery out of commission.*

1. When a battery is to remain idle for a considerable period, the cells may be dried off and the battery taken out of commission. Before doing so, all the plates must be brought into a thoroughly healthy condition, and the electrolyte must have attained its maximum constant specific gravity.

2. **Drying-off.**—The process of drying-off may be done in either of two ways. In the first method, the cells are discharged at the 10-hour rate to an average of 1·8V per cell. The acid is then drawn off into carboys and the cells are filled

with distilled water. This water is allowed to remain in the cells for 36 hours ; it is then syphoned off and the plates left to drain.

In the alternative method, the cells are fully charged and given about one hour's over-charge at half the normal rate. The acid is then drawn off into carboys, and the plates are thoroughly washed in at least two, or preferably three, changes of distilled water. The last filling of distilled water is allowed to stand in the cells for at least 24 hours. The plates are then taken out and allowed to drain.

Some manufacturers recommend methods which differ in some details from either of the above methods. It is, therefore, advisable to consult the makers of the battery as to the precise procedure to be adopted.

3. **Storage.**—While the plates are still moist the spongy growth on the negatives should be carefully washed off ; if the lead gauze bulges, it should be pressed flat by gentle pressure applied simultaneously to each side of the plate.

Wooden separators should be carefully examined to ascertain whether they are suitable for future use, and, if found suitable, they should be stored in acidulated water. If new separators are required, they should not be provided until the battery is to be brought into use again, and should then be inserted in the cells before the new electrolyte is put in.

The sediment should be cleaned out of the boxes and returned to the battery manufacturers. If new plates are bought at the same time, the makers will give an allowance off their cost for sediment, and also for old plates.

The plates should be dried off in a cool, dry place, free from dust, dirt, or other foreign matters.

The plates, when dried off, should be stored in their boxes ; if glass separators are used, they should be fitted in their places between the plates. The tops of the boxes should then be carefully covered with stout brown paper to keep out extraneous matter. Periodical inspection will be necessary to ensure that moisture has not attacked the plates in any way.

If the battery is to be moved by rail after drying out, the surfaces of all plates must be protected by varnished paper and the plates must be well packed between wooden boards. If time is available before packing and dispatch, apply to the C.I.R.E.S., Woolwich, for detailed instructions and advice.

It should be noted that a battery may be moved by road without being dried out. In such a case, the cells should be fully charged. About half of the electrolyte should then be poured off and the top of the cells packed tightly with clean cotton waste. The cells should be bedded in sawdust to within about 2 inches from their tops, at least 6 inches of sawdust being underneath and between cells. On arrival at the destination, all sawdust and cotton waste should be carefully removed; the cells should then be topped up and brought into action as soon as possible.

4. When a battery is brought into commission again after the cells have been dried off, the acid that was drawn off should be used again. If this acid is not available, fresh acid *of the same specific gravity* should be utilized.

Before being taken into general use the battery should receive a complete charge, at the normal rate or the rate specified by the makers.

119. *Battery room.*

1. It is a great mistake to suppose that any place into which the cells of a secondary battery can somehow be squeezed will be as suitable as a properly-designed and well-situated room. The general arrangement of the cells has already been discussed (Sec. **99**, para. 1); but it is as well to note that, when two rows of cells are placed side by side and the rows are long ones, there may be considerable P.D. between the two cells at the end of the rows, and an attendant, when working on one of these cells, might get a severe shock. A space of from 6 to 9 inches, or even more when the cells are deep, should, therefore, be left between the rows.

Pl. **127** shows a typical battery room.

2. **Site.**—The first requirement is that the room should be so situated that the acid is not brought into contact with injurious atmospheric impurities. Ammonia being a most dangerous impurity, the neighbourhood of stables, &c., should obviously be avoided.

3. **Floor.**—Concrete is now generally used, but it must be remembered that it does not resist acid very well, and this is of particular importance in the case of reinforced concrete, where the acid may get at the reinforcing metal and cause serious trouble. Consequently, it is advisable to provide some covering which is both acid-resisting and capable of bearing substantial weights. Vitrified brick, grouted in with gas-tar, pitch, or some bituminous compound, is suggested for such covering, though tiles are suitable. Provision should also be made for drainage, so that the room may be thoroughly washed out.

4. **Ventilation.**—Efficient ventilation is necessary to liberate the gases, cool the atmosphere, and prevent excessive evaporation of the electrolyte. Draughts should, however, be avoided.

PLATE 127. [To face p. 498.

BATTERY ROOM.

5. Temperature.—It is important to maintain an even temperature in the battery room as far as possible. About 80° F. is the maximum desirable temperature and 45° F. the minimum.

6. Lighting.—To allow of proper examination of the battery at all times, it is important that the room should be well lighted. North light is desirable, and direct access of the sun's rays to the cells should be avoided.

Electric light with lead-covered wiring is the best artificial lighting.

No naked lights or smoking should be allowed in the battery room.

7. Protection from acid spray.—All woodwork and metal work should be protected by black tar varnish. Lamps or fittings should not be placed directly over a row of cells. It is possible to procure specially designed shades and fittings which are only very slightly affected by acid spray.

120. *Nickel-iron cells.*

1. Cells employing an iron negative plate and a nickel-oxide positive plate with an alkaline electrolyte have been in use for over twenty years, but have never replaced the lead accumulator to any extent for reasons which will appear.

From the military point of view such cells have two great advantages :—

(1) They can be left without attention for long periods in a nearly fully charged condition, and so can be kept in peace time in mobilization store (*cf.* Sec. **115**, para. 3).

(2) They can be left for some time when discharged before being re-charged. In the 1914–1918 War large quantities of the lead portable batteries had to be scrapped after one discharge owing to the impossibility of getting them to a charging base before they were ruined by sulphation.

For these reasons alkaline accumulators deserve attention and will be considered in this section.

2. There are two types of alkaline cell :—

(1) Edison type, employing iron as the negative electrode.

(2) Jungner type, employing a mixture of cadmium and iron as the negative electrode. This is the type made in this country.

Both employ positive plates consisting of nickel oxides, and an electrolyte of potassium hydroxide.

The iron-cadmium powder is prepared by electro-deposition, and is enclosed in pockets of perforated nickel-steel ribbon. The positive plate consists of similar pockets containing the nickel hydroxide, mixed with flake graphite to increase the conductivity.

The following notes apply more especially to the Jungner type, of which the " Nife " and the " Alklum " cells are examples. Edison cells are not used for service purposes.

3. Exact equations showing the chemical action of these cells cannot be formulated.

The amount of water remains constant and the density of the electrolyte does not change.

In addition, owing to the fact that the potential required to evolve hydrogen by electrolysis is less than that necessary to reduce the negative plate, gassing takes place continuously during charge.

The theory of the action of the cadmium in the Jungner positive is obscure.

4. **Construction.**—Pl. **128** shows the construction of a small cell. Welded steel containers are used, packed in a wooden crate. As these steel containers are in contact with the electrolyte they attain a certain potential relative to the plates, and where several cells are used to form a battery, have to be insulated from one another and from the crate. One method of doing this is to support the cells from steel bosses fitting into ebonite insulating bushes which in turn fit into recesses in the crates.

The action of the air is detrimental to the plates, and consequently cells have screwed filling vents, with only a small escape (sometimes a non-return valve) for the hydrogen which is continuously evolved during charge. As this forms an explosive mixture with air adequate ventilation of the battery room is even more necessary than with lead cells.

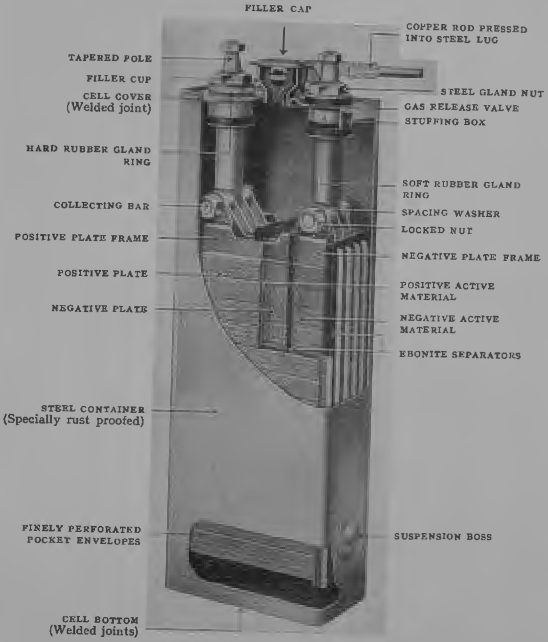
5. **Voltage.**—Charge and discharge voltage curves. are given in Fig. 101.

It will be seen that there is a big fall in voltage during discharge, from 1·4 to 1·0 during a normal 8-hour discharge, and that at the end of charge the voltage rises to 1·75. Normal practice is to complete the charge in 6 hours.

6. **Efficiency.**—Owing to this fall in voltage the energy efficiency of alkaline accumulators is low; 55 per cent. for the watt-hour and 70 per cent. for the ampere-hour efficiency being usual figures.

7. **Life.**—In order to obtain good lasting qualities it is essential that the ingredients of the plates should be absolutely pure. A good battery may be expected to go through 300 cycles without a loss of capacity of more than 10 per cent., but individual cells vary very considerably in this respect.

THE "NIFE" ACCUMULATOR.



[*Permission of Batteries, Ltd.*

8. Capacity.—Nickel-iron cells are made in sizes up to 450 ampere-hours at the 8-hour rate. At low temperatures the capacity falls off very seriously; at 5° C. no useful discharge down to a p.d. of 1 volt can be obtained from an Edison type cell, and for this reason the Edison type is useless for service purposes. Jungner type cells maintain their capacity better at low temperatures, but even with them the capacity at 40° F. is only about one-third of that at 77° F.

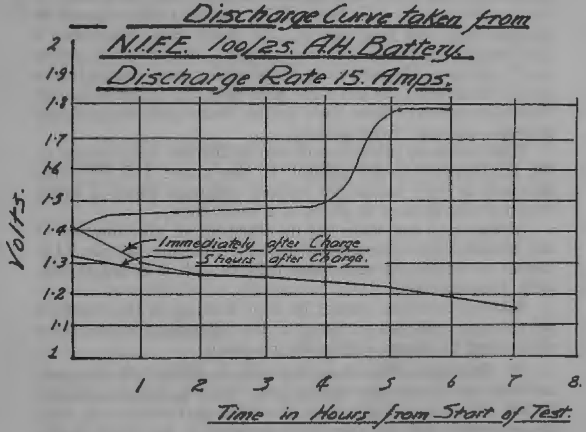


Fig. 101.

A fully charged cell will lose 8–10 per cent. of its capacity if left to stand idle for 24 hours, but will subsequently only lose capacity at a slow rate.

9. Management and maintenance.—First charge Jungner cells on being taken into use should be filled with electrolyte of a specific gravity of 1190 to the correct level, and then charged at the normal rate for double the usual length of time (*i.e.*, 10 or 12 hours).

The same treatment should be given to a battery that has been standing idle for a long time. If the battery does not then give its full capacity this double charge can be repeated twice with 50 per cent. discharges between the charges.

Since the specific gravity of the electrolyte does not alter during the discharge, and gassing takes place continuously during charge, neither criterion can be taken as any indication of the state of the battery. The voltage-time curve during discharge is near enough to a straight line for the voltage on closed circuit to be a rough guide to the capacity left in the battery, but the only reliable method of determining when the charge is complete is to fix an ampere-hour meter permanently in circuit, and put in 30 per cent. more ampere-hours than are taken out.

Topping up of the electrolyte with distilled water will be necessary once every few weeks. Every year, or whenever the specific gravity falls below 1170, the electrolyte should be emptied out and new put in. In doing this, the maker's instructions should be followed closely; the essential points are to discharge the cells completely, and to wash out all traces of the old liquid. At the same time that this is done all cells should be removed from their crates, thoroughly cleaned and greased, and the crates painted.

High charging rates do no harm to alkaline cells as long as the temperature is not allowed to rise above 115° F. This property is very useful for battery vehicles, where a rapid boosting charge may be given in a short time.

Charging at low rates has no effect on an alkaline cell of the Edison type. Consequently trickle-charging (*see* Sec. **114**) cannot be employed with these cells though it is practicable with Jungner cells.

Alkaline batteries cannot be kept floating on the bus-bars for voltage regulation purposes, as the difference between their charge and discharge voltages is too great.

10. **Storage.**—Before storing, cells should be fully charged, and then 20–25 per cent. discharged. They may subsequently be left for a considerable time, provided that every year they are inspected, and the electrolyte renewed as described above.

11. The relative merits of alkaline and lead cells are summed up in the following table :—

Advantages of alkaline cells.	Advantages of lead cells.
1. Simple and cheap maintenance. 2. Ease of storage. 3. Ability to remain discharged without damage. 4. Ability to withstand high rates of charge (*e.g.*, 4 times the normal rate for 15 minutes). 5. Maintains nearly normal capacity at high rates of discharge.	1. Cheaper. 2. More efficient. 3. Smaller for a given watt-hour capacity. 4. Fewer end-cells necessary. 5. Can be "floated" on the bus-bars and trickle charged. 6. Hold their capacity better at low temperatures. 7. Maintain a more uniform voltage during discharge.

121. *Accessories.*

1. **Hydrometers, secondary cell** are used for measuring the specific gravity of electrolyte. They are graduated to read from 1·150 to 1·250, 1·000 being the density of water.

Care must be taken in reading these instruments. They must float freely without touching plates or the side of the container, and the reading should be taken at the true surface of the liquid, and not at the top of the meniscus which will be formed.

2. **Voltmeter, D.C., secondary cell, 3 volts.**—This is a central-zero instrument with a pair of spears, which reads accurately to 0·025V at any part of the scale. It is used to ascertain the voltage of individual cells for record or other purposes.

3. **Thermometers, secondary cell** are of glass and have a range of from 0° to 130° F. Two should always be kept in the battery room, one for recording the temperature of the room and the other for ascertaining the temperature of the electrolyte in the cells.

4. **Lamps, electric, inspecting, secondary battery** are issued complete with **Bulb, electric, 4 volt, D.** Two should always be available in the battery room for the inspection of plates.

5. **Pole indicator.**—This is an electrolytic instrument and is issued in a leather case. It comprises a glass tube containing a liquid, into which project two platinum wires. On the passage of a current, the portion of the liquid in the vicinity of the negative pole assumes a purple tinge. On cessation of the current, the liquid regains its normal appearance.

6. **Syphons, secondary cell,** are no longer a Service store. Rubber tubing and glass separator tubes should be used to syphon the electrolyte from cells, when necessary. *Tubing, rubber, ⅜-in.*, may be demanded for this purpose.

7. **Electrolytic water tester.**—This is an instrument for rapidly testing the purity of water used for make-up purposes. It consists of a milliammeter connected in series with a 230-volt supply and with two electrodes which are immersed in the water to be tested. Distilled water is a non-conductor, but impurities make the water conducting, and if a big deflection is observed the water is unsuitable and should be analysed.

8. **Table of instructions.**—A printed table of instructions is supplied with all batteries and should be hung in the battery room. This contains detailed instructions for working

the battery, and gives the normal (10-hour) and 3-hour rates of discharge, and minimum voltage of individual cells at end of discharge with these currents flowing; the normal and maximum rates of charge, and approximate voltage of cells at end of charge at these rates; and the correct specific gravity for the electrolyte in the cells. These instructions should be carefully followed throughout the life of the battery.

BIBLIOGRAPHY.

The A.B.C. of Storage Battery Management. E. C. Mackinnon. 3*s*. 6*d*.

Storage Battery Practice. R. Rankin.

Alkaline Accumulators. J. T. Cresswell. 10*s*. 6*d*.

D.W. Standard Specifications for E. & M. Services :—

No. 16. Secondary Batteries, Lead-Acid Type.

APPENDIX I.

CENTRAL ELECTRIC POWER STATION, ALDERSHOT COMMAND.

Cost of Production Account.

(*Year ending* 31*st March*, 1929.)

Total Number of Units supplied : 5,758,044.

Item.	Cost.		Cost per unit supplied.	
	£.	£.	d.	d.
Generating charges.				
Fuel	9,730	—	0·41	—
Lubricants, waste, E.R. stores, and water	830	—	0·04	—
Labour, civilian	6,793	—	0·28	—
Repairs and maintenance of buildings	31	—	0·00	—
Repairs and plant and machinery	660	—	0·03	—
Depreciation of buildings ..	588	—	0·02	—
Depreciation of plant and machinery	3,704	—	0·15	
Interest on capital. Building and plant	4,880	—	0·20	—
		27,216		1·13
Distribution charges.				
Labour, civilian	2,063	—	0·09	—
Repairs and maintenance of mains, &c.	513	—	0·02	—
Depreciation of mains, &c. ..	3,478	—	0·14	—
Interest on capital	5,063	—	0·21	—
Miscellaneous	178	—	0·01	—
		11,295		0·47
Administration charges.				
Engineer's salary	710	—	0·03	—
Clerical staff, draughtsman, &c.	1,152	—	0·05	—
Supervision	214	—	0·01	—
Office expenses and travelling	191	—	0·01	—
Barrack services	161	—	0·00	—
		2,428		0·10
	Total ..	£40,939	—	1·70

APPENDIX II.

Army Form N.7534.

The Annual Account is to be furnished by the Officers in Charge of Electricity Supply Systems not later than three weeks after the 31st March of each year, for transmission to War Office through Command Headquarters within 28 days of the end of the year.

Operation Account of ELECTRICITY SUPPLY SYSTEM for the period 1st April 1929 to 31st March 1930

Command......Southern **Station**......Tidworth

C.E...................Command.

Forwarded.

..........19 . C.R.E...............

D.W.

Forwarded.

..........19 . C.E.................

INSTRUCTIONS FOR THE COMPILATION OF A.F. N.7534.

1. Fuel consumption from the monthly log book of the Station Engineer (reconciled periodically with Army Form F.771) priced at the average (delivered) rate for receipts during the period as ascertained from Officer i/c Barracks and taking into consideration quantity and price of opening and closing stocks.

2. Lubricants, waste, &c., value of consumption in period, priced at vocabulary, &c., rates. Water, if from W.D. mains, at 6*d.* per 100,000 foot gallons (1,000 gallons raised per 100 feet) ; from other mains at cost.

3, 7, 11 and 12.

(*a*) Military personnel posted for duty will be apportioned between A and B, according to duties, and will be charged at the following weekly rates without deduction of time spent on military duties, sick or other leave, except embarkation leave or leave before taking up and after finally relinquishing duty. Casual employments of military personnel will be charged for at $\frac{1}{7}$ of these rates for each day of employment. The cost of R.E. linemen will be charged to item 8.

Military mechanists	£5	19	0
Sergeants	4	4	0
Corporals (and lance-sergeants)	3	10	0
Sappers or privates (and lance-corporals)	2	9	0

(*b*) Civilians at cost, apportioned between A and B, according to duties.

4 & 8. Repair and maintenance charges ascertained from D.C.R.E. (or G.E.), plus 15 per cent. overheads. Includes also nuts, bolts, washers, packing, emery, tape, &c., and all stores for repairs carried out by operating staff of the Station. (The cost of the labour of the operating staff while engaged on repairs remains charged to items 3 and 7.)

Renewal expenditure will not be charged to this account, but will be debited to the Depreciation Reserve Account of the asset concerned.

Item 4(*b*) also includes cost of replacement (receipts, less value of returns) of tools on charge, and a hiring charge of 10 per cent. per annum on value of tools on loan from R.E. Stores.

5 & 9. The actual installed cost of the following assets will be written off to Revenue at the annual depreciation rates shown below, except that, in the case of plant, a scrap value assessed at 10 per cent. of original cost will remain in the Capital Account while the asset is held. (For assets existing on 1st April, 1929, the existing standard capital replacement values will be used and the depreciation rates will be charged until the asset is disposed of.)

Plant	5	per cent. per annum
Mains	3	,, ,,
Meters	5	,, ,,

For buildings, an annual charge of 2½ per cent. (which includes 1 per cent. contribution in lieu of rates) calculated on the capital values will be debited to item 5(*a*). For buildings existing on 1/4/29, the present standard capital replacement values will be used. For buildings erected subsequent to 1/4/29, the annual charge will be calculated on the actual cost.

Interest at 5 per cent. per annum will be charged on the capital value of the assets referred to in this instruction.

13. Represents estimated cost of supervision of C.R.E., D.C.R.E., G.E., E. & M.O., I.R.E.M. and their staffs as assessed by C.R.E. for each station separately.

14. Postages from Army Book 97. Stationery: receipts in period calculated in accordance with A.C.I. 75/1927; for issues not falling under the A.C.I., and hiring charges for typewriters at rates on Army Form L.1395. Includes telephone rentals and calls at local G.P.O. rates. Travelling from Army Form O.1771 or railway warrant book (priced by R.A.P.C. clerk).

15. Barrack services ascertained from Officer i/c Barracks. Hiring charge for furniture on inventory on the first day of each quarter at 5 per cent. per annum on vocabulary value. Cost of soap, soda, cleaning materials, &c., acertained from the expense vouchers. Cleaning allowance from Army Form N.1531.

16. (*a*) Priced at 3*d.* per **kWh.**

17. (*a*) Includes W.D. civilian employees.

22. Amendments to capital values due to additions to or deductions from buildings, plant, etc., will be made as from the commencement of the quarter in which the alterations occur.

NOTES.

1. Fractions of £1 under 10*s.* to be excluded from this account; amounts of 10*s.* or over to be rounded up to next £ above.

2. A note will be attached to the account explaining any material variations between this period's costs and the costs for the last year or corresponding period of last year.

Dr.

System See page 40 Fuel Heavy Oil

Engineer-in-Charge

	This period					Last year or corresponding period last year		
				Cost per kWh (to 2 decimal places)			Cost per kWh (to 2 decimal places)	
	£	s.	d.	Generated d.	Supplied d.	£	Generated d.	Supplied d.
A. GENERATING CHARGES.								
1. Fuel (including delivery cost)	3,139	0	0	0·24	0·31			
2. Lubricants, waste, engine-room stores and water	944	0	0	0·07	0·09			
3. Labour.								
(*a*) Military	—			—	—			
(*b*) Civil	2,965	0	0	0·22	0·29			
4. Repairs and maintenance of								
(*a*) Buildings	5*	0	0	—	—			
(*b*) Plant, machinery and tools	1,223	0	0	0·09	0·12			
5. Depreciation, &c.								
(*a*) Buildings (rentals and rates)	188	0	0	0·01	0·02			
(*b*) Plant and machinery ..	2,299	0	0	0·17	0·22			
(*c*) Interest on capital (£53,480 @ 5%) ..	2,674	0	0	0·20	0·26			
6. Other charges (to be specified)	12	0	0	—	—			
Total Generating Charges ..	13,449	0	0	1·00	1·31			
B. DISTRIBUTION CHARGES.†								
7. Labour.								
(*a*) Military	—			—	—			
(*b*) Civil	1,052	0	0	0·08	0·10			
8. Repairs and maintenance of								
(*a*) Mains	2,001	0	0	0·15	0·20			
(*b*) Meters	62	0	0	—	—			
(*c*) Sub-station buildings ..	—			—	—			
(*d*) Sub-station equipment ..	7	0	0	—	—			
9. Depreciation, &c.								
(*a*) Sub-station buildings ..	32	0	0	—	—			
(*b*) Sub-station and switch-gear	211	0	0	0·02	0·02			
(*c*) Mains	2,210	0	0	0·17	0·22			
(*d*) Meters	258	0	0	0·02	0·03			
(*e*) Interest on Capital .. (£84,360 @ 5%) ..	4,218	0	0	0·32	0·42			
10. Other charges (to be specified)—								
Transport	25	0	0	—	—			
Travelling allowances and wayleaves	146	0	0	0·01	0·01			
Total Distribution Charges ..	10,222	0	0	0·77	1·00			
C. ADMINISTRATIVE CHARGES								
11. Engineer.								
(*a*) Military	—			—	—			
(*b*) Civil	866	0	0	0·07	0·08			
12. Clerical staff, draughtsmen, &c.								
(*a*) Military	—			—	—			
(*b*) Civil	180	0	0	0·01	0·01			
13. Supervision	141	0	0	0·01	0·01			
14 Office expenses and travelling	183	0	0	0·01	0·01			
15. Barrack services, &c.	14	0	0	—	—			
Total Administrative Charges	1.334	0	0	0·10	0·14			
TOTAL CHARGES, A, B and C ..	25,005	0	0	1 87	2·45			
BALANCE								
TOTAL								

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* In 1928–29, £237 was spent under this head.

† Distribution charges end at consumers' meters inclusive.

Cr.

	This period			Last year or corresponding period last year		
	kWh supplied	Rate *d.*	£	kWh supplied	Rate *d.*	£
D. CREDITS.						
16. Current supplied on public service						
(*a*) W.D. units and establishments	1,799,452	3·00	22,492			
(*b*) Air Ministry	14,715	2·93	180			
(*c*) Other Government Depts. (to be specified)	199,646	2·75	1,872			
G.P.O. (Lighting)	1,756	3·00	22			
Board of Agriculture (Lighting)	31	3·00	—			
„ „ (Power)	1,460	3·12	19			
17. Current supplied to other consumers on repayment :—						
(*a*) Military (Lighting) ..	142, 629	3·34	1,988			
„ (Power)	4,986	3·22	67			
(*b*) Civilian (Lighting) ..	197,681	3·32	2,735			
„ (Power)	24,284	3·19	323			
18. Current supplied in bulk on repayment :—						
Durrington Supply Company ..	38,615	2·38	383			
19. Rental of W.D. meters (or other apparatus) on consumers' premises	—	—	324			
20. Other credits (to be specified) :—						
Additions to claims of repayment consumers (A.C. I 435/28, para. 4)	—	—	111			
Stabling horses	—	—	55			
Charging accumulators ..	—	—	41			
Reconnecting W.D. meters ..	—	—	1			
Non-cash—						
Charging accumulators ..	—	—	8			
Distilled water	—	—	7			
TOTAL CREDITS D	2,425,255		30,623			
BALANCE						
TOTAL						

21. TECHNICAL DATA

	Plant installed k.W.	Batteries installed A.h.	Load installed k.W.			Max. demand k.W. (a)	kWh generated	kWh supplied	% of kWh generated				Load factor % (b)	Thermal efficiency (c)
			Power	Lighting	Total				Consumed in station		Lost in distribution			
									Units	%	Units	%		
This period	1,620	1,500				1,050	3,185,910	2,425,255	361,900	11.3	398,755	12.5	36.4	25.2
Last year or corresponding period last year														

22. CAPITAL VALUES.

	This period		Last year or corresponding period last year	
	Generation £	Distribution £	Generation £	Distribution £
Buildings	7,500	1,500		
Plant and machinery	45,824	4,811		
Mains and feeders	—	37,513		
Distributors	—	36,227		
Meters	—	5,164		
TOTAL	53,324	85,215		

23. AVERAGE DAILY STRENGTH OF PERSONNEL (items A.3, B.7, C.11, and 12).

	NUMBERS			
	This period		Last year or corresponding period last year	
	Military	Civil	Military	Civil
(i) Direct labour		—		
(a) Generation		14·82		
(b) Distribution		6·89		
(ii) Engineers		1·81		
(iii) Clerks and draughtsmen		1·00		
TOTAL		24·52		

(a) The MAXIMUM DEMAND will be twice the number of kWh generated during any consecutive thirty minutes during the period, *i.e.* with station losses excluded.

(b) The LOAD FACTOR expressed as a percentage, will be the total kWh generated × 100 divided by the product of the maximum demand and number of hours in the period (not the number of hours the plant was run).

(c) The THERMAL EFFICIENCY $= \dfrac{\text{Units generated} \times 341{,}200}{\text{lbs. fuel used} \times \text{calorific value}}$

APPENDIX III.

ELECTRIC SUPPLY STATION, PEMBROKE, MALTA.

(*Year ending* 31*st December*, 1926.)

TOTAL UNITS GENERATED: 67,709.

Generating costs.

Item.	Cost.	Cost per unit generated.
	£	*pence*
Fuel oil	287	1·02
Lubricating oil	28	0·10
Maintenance	31	0·11
Wages	421	1·49
Depreciation	320	1·14
Miscellaneous	74	0·26
Total	£1,161	4·12

APPENDIX IV.

METHOD OF TREATMENT FOR ELECTRIC SHOCK.

(*As recommended by the Royal Life Saving Society.*)

First secure release from contact.

To free from contact.—Note carefully and quickly the surroundings; then avoiding contact with any live conductors, and using great caution if high voltages are involved, pull the patient away, if practicable; if not, break the circuit. To pull the patient away avoid actual contact with the skin; use rubber gloves if at hand, or pull by a loose part of the coat (even this may be dangerous in case of high or extra high voltage) or by any non-conducting dry material available, such as a loop of rope, a coat, broom-handle, or crooked stick. If the patient is holding any portable electrical apparatus pull out the plug of the connector.

After release from contact.—Place the body on a dry floor or table, or dry straw, and, if no sign of breathing can be observed, immediately proceed to promote artificial breathing.

To promote artificial breathing proceed as follows :—

1. Turn the patient face downwards.

2. Kneel at his side and place your hands flat in the small of his back with thumbs nearly touching and the fingers spread out on each side of the body over the lowest ribs.

3. Then promote artificial breathing by leaning forward over the patient, and without violence produce a firm, steady, downward pressure. Next release all pressure by swinging your body backwards without lifting your hands from the patient.

4. Repeat this pressure and relaxation of pressure as directed in Clause 3, without any marked pause between the movements, about fifteen times a minute, until natural breathing is established.

5. The efforts to restore breathing must be carried out with perseverance, as life has been restored after a long period.

Points to remember.

1. In all cases send for medical assistance as soon as possible.

2. Any burns should be treated with an oil dressing, and covered from the air.

3. Stimulants should not be administered unless recommended by a medical man.

APPENDIX V.

SCALES OF ELECTRIC LIGHTING.

(Extract from Barrack Synopsis.)

The scales of electric light allowed in various rooms, &c., are given in the table below.

The candle power of electric lamps deteriorates with use, and falls considerably if voltage is appreciably below that for which the lamps are designed. It is important that the lighting installed should be fully up to the authorized scale.

" Pearl " or internally frosted lamps will be used in all cases except where there is a special reason for using clear lamps.

The best height for an electric lamp is 9 ft. to 10 ft. 6 ins. above the floor.

External Lighting.

The amount of external lighting should not usually exceed 4 per cent. of the internal lighting of Barracks.

Scales of Lighting in Terms of Floor Area.

Rooms, &c.	Sq. ft. per Watt.	Remarks. L.A.R.=Lights as required. S.L.A.R.=Small lights as required. N.L.A.=No light authorized.
GENERAL		
Entrances, corridors, and staircases.	—	S.L.A.R. Generally not exceeding 1 watt per 16 sq. ft. and 400 sq. ft. per lamp.
Kitchens, sculleries, pantries and services.	6	
Lavatories, W.C.s, urinals, and bathrooms.	—	S.L.A.R.
Verandahs	—	S.L.A.R. where used for sleeping or eating. Generally not exceeding 1 watt per 16 sq. ft. and 400 sq. ft. per lamp.
MESSES		
Mess and ante-rooms, officers'	3	
Mess and reading rooms, sergeants'.	4	
Billiards rooms	4½	For area of room minus table. For table 66–60 watt or 2–100 watt lamps according to type of fitting.
Cellars, liquor stores, &c. ..	—	S.L.A.R. Generally not exceeding 1 watt per 16 sq. ft. or 400 sq. ft. per lamp.

Rooms, &c.	Sq. ft. per Watt.	Remarks. L.A.R.=Lights as required. S.L.A.R.=Small lights as required. N.L.A.—No light authorized.
MESSES—*continued.*		
Waiters' day rooms	5	
Cooks' rooms	6	
QUARTERS		
Living rooms, single officers'	3	1 fixed light and 1 table lamp, and 1 wall socket and plug.
Bed rooms, single officers'	6	1 fixed light and 1 wall socket and plug.
Servants' rooms, single officers'	6	
Living rooms, married officers'	3	In addition to the normal fixed lights, 3 of the rooms in each married officer's quarter should be fitted with a wall plug, and table lamps should be provided on the following scale :— Group III Quarter—2, Group IV or Group V Quarter—1.
Bed and dressing rooms, married officers'.	6	
Bed rooms, servants'	8	
Living rooms, married W.O.'s and soldiers'.	5	With minimum of 40 watts in the living room of a W.O.'s quarter, 1 table lamp and 1 wall plug may be given in addition.
Bed rooms, married W.O.'s and soldiers'	8	
BARRACK AND MISCELLANEOUS		
Ablution rooms	8	1 light per 10 ft. run of bench.
Bath houses	8	1 light to every 2 bath rooms.
Barrack rooms	5	
Boiler houses	—	S.L.A.R. Wall socket, plug and hand lamp should be provided where necessary.
Cook houses and preparation rooms.	6	1 light per cooking apparatus.
Church rooms	3	
Detention barracks	—	As in ordinary barracks. In "special" detention rooms the lamp box is fixed over the doorhead.
Detention rooms	—	1 small light per room in lamp box.
Dining rooms	5	1 light per pair of sinks in wash-up.
Drawing offices	1	Lights to be of the "day lamp" or "rest lamp" type with adjustable suspension.
Educational buildings	—	*See* "Schools."

Rooms, &c.	Sq. ft. per Watt.	Remarks. L.A.R.=Lights as required. S.L.A.R.—Small lights as required. N.L.A.—No light authorized.
BARRACK AND MISCELLANEOUS —*continued.*		
Fire engine sheds	—	S.L.A.R.
Guard rooms	5	
Gymnasia—Hall	2	Height above floor level at least 18 ft.
,, Dressing rooms	8	
,, Instructor's room	5	
,, Fencing room ..	3	
Institutes	3⅛	Average figure for whole area. The arrangements by rooms to be settled in collaboration with N.A.A.F.I.
Laundries—Wash house ..	6	
,, Ironing room ..	4	
Miniature ranges	—	At the target end, 300 watts for every 24 ft. width of range in " flood light " or similar fittings. At the firing point end, one 40 watt lamp over the firing point and one 60 watt lamp for spectators.
Offices	4	
Preventive ablution centres ..	—	S.L.A.R.
Riding schools	3	
Schools—Class rooms ..	3	
,, Teachers' rooms ..	4	
,, Cloak rooms ..	11	
,, Book, &c., stores ..	8	
Sergeants' rooms	4	With minimum of 25 watts.
Stables	—	1 small light to 2 stalls or in each loose box.
Stables—Saddle or harness rooms.	11	
,, Forage stores ..	—	N.L.A.
,, Expense forage stores.	—	S.L.A.R.
,, Coach houses ..	16	
Stores	11	Also in the case of reservist mobilization stores 1 wall plug per 750 sq. ft. floor area, and 1 hand lamp for every two wall plugs.
Vehicle sheds (M.T. or tanks)	8	Also 1 wall plug per bay for inspection lamps.
Workshops	—	L.A.R. Usually general lighting of 5 to 8 foot candles on the working plane, and lights for individual machines if necessary.

ELECTRIC LIGHTING IN HOSPITALS.

Hospital scales are not laid down in the Barrack Synopsis.

The following table shows the scale of lighting which should be provided.

Quarters, rooms, &c., not specifically mentioned in this table will be dealt with in accordance with the scales laid down in the Barrack Synopsis.

(D.W.T.I. No. 350.)

Rooms, &c.	Sq. ft. per Watt.	Remarks. L.A.R.=Lights as required. S.L.A.R.=Small light as required.
Annexes, lifts, telephone room, passages.	—	S.L.A.R.
Stores—		
Bread, groceries, meat, medical, comfort, milk, vegetables.	11	
Test room	—	L.A.R.
ACCESSORY AND STAFF BUILDINGS		
Discharge block	6	
Disinfection establishment ..	—	L.A.R.
Mortuary	—	L.A.R.
Sleeping and soiled linen room	—	S.L.A.R.
Quarters for staff, and machinery accessory buildings.	—	*See* Barrack Synopsis.
ADMINISTRATION BLOCK		
Board room	4	
Clinical laboratory	3	In addition, wall socket and table lamp for bench work.
Consulting room	3	In addition, wall socket and hand lamp.
Dispensary	3	
Orderly medical officer room	4	
Stores—		
Drug	4	
Quartermasters'	6	
District (Hygiene) Laboratory	3	In addition, wall socket and hand lamp.
Medical inspection room—		
Consulting room	4	
Dispensing room and drug store.	4	
Reading room	4	
Waiting room	6	
Wash-ups	6	
Larders	—	S.L.A.R.
Nursing duty rooms	4	
Nurses' retiring room ..	6	

Rooms, &c.	Sq. ft. per Watt.	Remarks. L.A.R.=Lights as required. S.L.A.R.=Small light as required.
ADMINISTRATION BLOCK—*continued.*		
Wards	6	In addition, one small reading lamp for each bed, the switch controlling the reading light to be of the combined switch and wall socket type for use with plug and lamp for special examination. One or more of the main lights should be of a special pattern for night use.
Operating room	—	L.A.R. Operating rooms will be specially considered in each case; for large operating rooms: the following should be installed :— (1) One wall plug for hand lamp. (2) Four bracket lamps on the walls of 60 watts each. (3) (*a*) Scialytic light, type "B," large model with adjustable suspension, wired for three emergency lights. (*b*) One 150 watt frosted bulb for main socket. Three 60-watt 25-volt frosted bulbs for emergency sockets. (*c*) Two 24 volt batteries for use alternately, each consisting of four 3-cell batteries (6 volt, 40–50 ampere-hour) in wood cases with carrying strap, or alternatively one battery and "Keepalite" or other suitable charging apparatus.
Anæsthetic room	4	
Preparation room	4	
Room for sterilizing dressings	6	
Robing room	6	
Röntgen Ray room	6	
Developing room	—	L.A.R.
Sisters' room	6	

APPENDIX

DETAILS OF WIRES

(Abstracted from I.E.E. Regulations for the Electrical Equipment

Nominal area.	Number and diameter of wires comprising conductor.	Current-carrying capacity.					
		Vulcanized rubber cables.			Impregnated paper lead-covered cables.		
		Single cables run in pairs.	Concentric or twin.	Three-core cables.	Single cables run in pairs.	Concentric or twin.	Three-core cables.
Sq. in.	Ins.	Amperes.	Amperes.	Amperes.	Amperes.	Amperes.	Amperes.
0·001	1/0·036	4·1	4·1	4·1	4·1	4·1	4·1
0·0015	1/0·044	6·1	6·1	6·1	6·1	6·1	6·1
0·002	3/0·029	7·8	7·8	7·8	7·8	7·8	7·8
0·003	3/0·036	12·0	12·0	12·0	12·0	12·0	12·0
0·003	1/0·064	12·9	12·9	12·9	12·9	12·9	12·9
0·0045	7/0·029	18·2	17·5	16·0	18·2	18·0	18·0
0·007	7/0·036	24·0	22·0	19·5	28·0	25·0	23·0
0·01	7/0·044	31·0	26·0	23·3	42·0	35·0	31·5
0·0145	7/0·052	37·0	31·0	27·0	57·0	45·0	41·0
0·0225	7/0·064	46·0	38·5	33·0	75·0	60·0	56·0
0·03	19/0·044	53·0	45·0	39·0	87·0	71·0	66·0
0·04	19/0·052	64·0	53·0	47·0	104·0	85·0	78·0
0·06	19/0·064	83·0	69·0	61·0	135·0	114·0	101·0
0·075	19/0·072	97·0	80·0	71·0	157·0	130·0	117·0
0·1	19/0·083	118·0	96·0	87·0	191·0	157·0	142·0
0·12	37/0·064	130·0	108·0	99·0	210·0	174·0	161·0
0·15	37/0·072	152·0	125·0	115·0	246·0	200·0	186·0
0·2	37/0·083	184·0	150·0	140·0	296·0	242·0	227·0
0·25	37/0·093	214·0	176·0	160·0	343·0	280·0	265·0
0·3	37/0·103	240·0	200·0	—	385·0	322·0	304·0
0·4	61/0·093	288·0	244·0	—	464·0	394·0	—
0·5	61/0·103	332·0	280·0	—	540·0	457·0	—
0·6	91/0·093	384·0	—	—	624·0	—	—
0·75	91/0·103	461·0	—	—	738·0	—	—
0·85	127/0·093	512·0	—	—	815·0	—	—
1·0	127/0·103	595·0	—	—	932·0	—	—

The figures for current-carrying capacity apply to cables used in the
for underground mains laid in pipes or ducts. For armoured cables laid

VI.

AND CABLES.

of Buildings, and in agreement with B.S.S. 7 of 1926.)

Conductor resistance per 1,000 yards at 60° F.	Minimum insulation resistance per mile at 60° F.			
	Vulcanized rubber cables.			Paper cables 660 volts.
	600 megohm grade 250 volts.	2,500 megohm grade 250 volts.	660 volt grade.	
Ohms.	Megohms.	Megohms.	Megohms.	Megohms.
23·59	2,000	5,000	5,000	140
15·79	2,000	5,000	5,000	140
12·36	1,250	4,500	4,500	140
8·019	1,250	4,500	4,500	140
7·463	2,000	5,000	5,000	140
5·281	1,250	4,500	4,500	140
3·427	900	4,000	4,000	140
2·294	900	4,000	4,000	140
1·643	900	4,000	4,000	140
1·084	900	3,500	3,500	130
0·8468	750	3,500	3,500	125
0·6063	750	3,000	3,000	115
0·4002	750	3,000	3,000	100
0·3162	600	3,000	3,000	85
0·2380	600	3,000	3,000	80
0·2056	600	3,000	3,000	75
0·1625	600	3,000	3,000	60
0·1223	600	2,500	2,500	55
0·09738	600	2,500	2,500	50
0·07939	600	2,500	2,500	50
0·05908	600	2,500	2,500	50
0·04816	600	2,500	2,500	45
0·03961	600	2,500	2,500	40
0·03229	600	2,500	2,500	40
0·02838	600	2,500	2,500	35
0·02314	600	2,500	2,500	35

internal wiring of buildings. They are about right, however, direct in the ground, *see* Appendix VII. *See also* Sec. **37**.

APPENDIX VII.

Approximate Safe Current-carrying Capacity for

L.V. 660V PAPER-INSULATED, LEAD-COVERED AND ARMOURED CABLES.

Laid direct in the ground.

The figures in this table are based on the result of a research carried out by the B.E.A.I.R.A.

Nominal area of conductor.	Number and diameter of wires comprising conductor.	One single cable.	One concentric or twin cable.	One three-core, four-core, or twin concentric cable.
Sq. in.	Inch.	Amps.	Amps.	Amps.
0·007	7/0·036	60	44	40
0·01	7/0·044	79	57	52
0·0145	7/0·052	100	72	66
0·0225	7/0·064	131	94	84
0·03	19/0·044	155	111	98
0·04	19/0·052	190	136	120
0·06	19/0·064	248	176	154
0·075	19/0·072	285	202	176
0·1	19/0·083	337	239	208
0·12	37/0·064	367	260	226
0·15	37/0·072	415	299	260
0·2	37/0·083	492	353	305
0·25	37/0·093	558	400	349
0·3	37/0·103	627	453	391
0·4	61/0·093	745	534	460
0·5	61/0·103	835	605	520
0·6	91/0·093	942	687	—
0·75	91/0·103	1,055	765	—
0·85	127/0·093	1,140	830	—
1·0	127/0·103	1,282	936	—

The table refers to situations in which cables are laid 18 inches deep in average moist ground, the temperature of which does not exceed 59° F., and allows for a temperature rise of 90° F., so that the maximum running temperature is 149° F. An allowance must be made for higher soil temperatures. For example, if the soil temperature is 77° F. the current-carrying capacity is reduced by 10 per cent.

The safe current-carrying capacity depends to some extent upon the wetness of the ground and may have to be reduced 15 per cent. if the soil is very dry. Owing to dielectric hysteresis losses, the safe current-carrying capacity falls slightly as the working voltage increases, being 6 per cent. less for 11,000 volts cable than for 660 volts.

An allowance must also be made for proximity effect, when two or more cables are laid side by side.

CORRECTIONS FOR GROUPING OF CABLES.

Distance between cable axes.	Multiplying factor.		
	2 cables.	3 cables.	4 cables.
Inches.			
4	0·76	0·70	0·65
12	0·87	0·80	0·75
24	0·93	0·90	0·85

APPENDIX VIII.

APPROXIMATE FUSING CURRENTS OF COPPER WIRES IN FREE AIR.*

Diameter of wire. 1.	Equivalent S.W.G. size. 2.	Fusing current. 3.	Maximum safe working current (*see* note). 4.
Inch.		Amps.	Amps.
0·0092	34	8·6	4·3
0·010	33	9·8	4·9
0·0108	32	11·0	5·5
0·0120	—	12·8	6·4
0·0124	30	13·5	6·8
0·0148	28	17	8·6
0·018	26	22	11
0·022	24	30	15
0·028	22	41	21
0·029	—	43	22
0·036	20	62	31
0·040	19	73	37
0·044	—	86	43
0·048	18	98	49
0·052	—	111	56
0·056	17	125	63
0·064	16	156	78
0·072	15	191	96
0·080	14	229	115

* *See* note at foot of Appendix IX.

APPENDIX IX.

APPROXIMATE FUSING CURRENTS OF LEAD-TIN ALLOY (LEAD 75 per cent., TIN 25 per cent.) WIRES IN FREE AIR.

Diameter of wire. 1.	Equivalent S.W.G. size. 2.	Fusing current. 3.	Maximum safe working current. (*see* note). 4.
Inch.		Amps.	Amps.
0·020	25	3	2·0
0·022	24	3·5	2·3
0·024	23	4	2·6
0·028	22	5	3·3
0·032	21	6	4·1
0·036	20	7	4·8
0·048	18	10	7·0
0·064	16	16	11·0

Note.—Appendices VIII and IX refer to wires in free air and of the following lengths :—*Copper :* 2½ to 3½ inches for wires up to 0·018 inch diameter ; and not less than 4 inches for larger wires. *Lead-tin Alloy :* 2½ to 3½ inches.

The values given in the tables may be taken to be correct where the fuse passes through an asbestos tube and does not closely touch the tube, but they do not apply where a substantial length of the wire is in contact with a porcelain holder. The tendency of the latter design is to increase the working capacity of the fuse, *i.e.*, more current is required to melt the fuse, and if great accuracy is required the fusing current should be determined for the fuse-holder in question.

For copper wires, the values of the currents given are those necessary to fuse the wire in one minute, and are not appreciably different for other periods (the current required to fuse the wire in two hours being, in general, over 90 per cent. of that required to melt the wire in one minute).

For the lead-tin alloy the currents given are those necessary to fuse the wire in two minutes.

In every case the relation between the fusing current and the maximum safe running is based on values which will not produce an excessive temperature under normal running conditions. The actual temperature-rise at the hottest part of the fuse wire will be from 100° to 150° C. for copper, and 50 to 75° C. for the lead-tin alloy.

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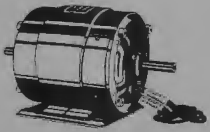

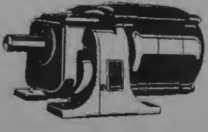

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