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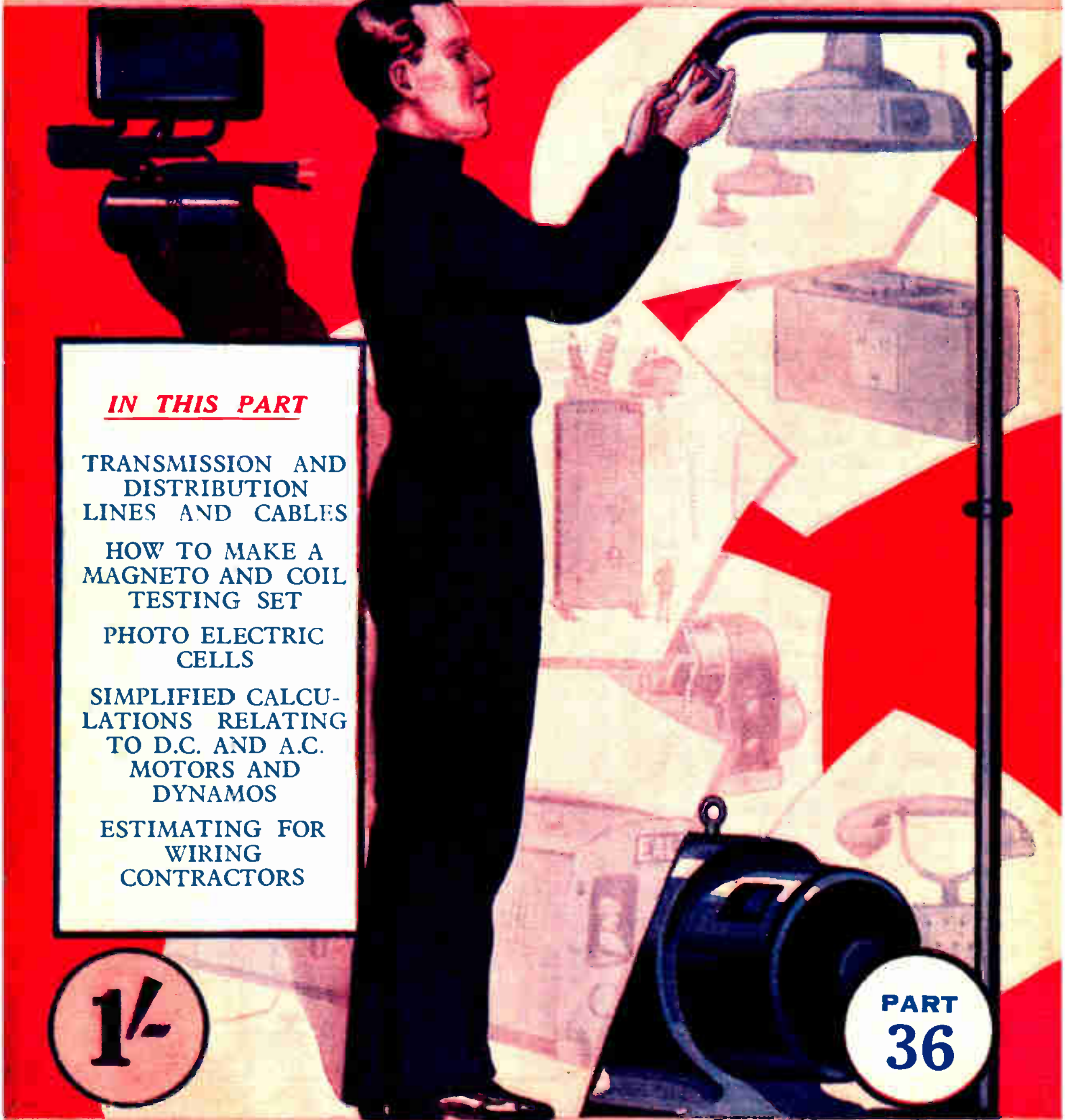

IN THIS PART

TRANSMISSION AND DISTRIBUTION LINES AND CABLES

HOW TO MAKE A MAGNETO AND COIL TESTING SET

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side being finished off with three or four twists. At angle positions, where the conductor will be in the side groove, a single stirrup of a modified shape is used.

When suspension insulators are used on steel-cored aluminium lines, see that the clamps are fitted with liners, or else put a layer of aluminium tape on the conductor.

JOINTS AND CONNECTORS.

If the conductors are delivered in standard manufacturing drum lengths, the latter will need to be jointed together in the field. These joints should not occur close up to an insulator and they must be approximately equal in strength to the conductor itself. The most popular tension joint is the McIntyre, shown in Fig. 19. It consists of an oval seamless tube of copper or aluminium from 30 in. to 48 in. long, depending on the strength and size of the conductor. In order to make the joint, fill the tube with graphite grease and thread the two conductor ends, which should be perfectly clean, through it.

The second end will be difficult to put through, so cut away all its strands except one for a length slightly greater than the length of the tube, thread through and pull the conductor into position. The tube has now to be twisted up, taking care that this is done in the correct direction, as otherwise the strands will open. Grip the tube in the twisting tongs at the centre and at one end, and gradually turn until 4½ to 5½ complete twists have been given. Repeat for the other half of the tube so that the finished joint has 9 to 11 twists. McIntyre joints are satisfactory for all sizes of copper, cadmium copper and steel-cored aluminium up to 0.1 sq. in. equivalent and for 7/12 S.W.G. teel and copper-cored steel conductors.

Cone Joint.

Another type of tension joint is the cone joint, of which there are several patterns available. As their name indicates these joints consist of two or more cones which grip the strands with a wedge action. They can readily be designed to develop the full strength of the conductor and can be used up to the largest conductor cross sections likely to be required. The making of these joints is very simple but generally careful and accurate marking and cutting of the strands is necessary. Fill cone joints by means of a grease gun with graphite grease, Stablex or compound when completed.

Connecting the Tails Together.

At straining insulator poles connect the tails together by parallel groove clamps of gunmetal, brass or pure aluminium. Paint the exposed ends of steel-cored aluminium with bitumastic. Instead of parallel groove clamps, cone clamps similar to the tension joints (but not designed for taking the tension) can be used, so as to avoid exposing the core of a steel-cored aluminium conductor.

It is extremely important that no copper or copper alloy be placed in contact with aluminium, or else rapid corrosion will occur. In fact, it may be said that all fittings, clamps and connectors must be

Fig. 33.—ERECTING L.T. POLE—SECOND STAGE.
The pole is being pushed up by the fork and steadied by the men at the pole hole.

A

Fig. 34.—Erecting a Transformer Platform and Drilling Holes for Fixing Switchgear.

See that a safety belt is used whenever men are up poles.

either pure aluminium or galvanised iron or steel. Where a copper tapping has to be taken off to a switch transformer or cable box, use a bi-metallic T connector, which is fitted with an insulating washer, between the aluminium body and the brass socket for the tail. When the load on the tapping is a small current one, galvanised parallel groove clamps can be used to connect the copper tail to the aluminium. Pole type cable dividing boxes can be obtained with aluminium stems and aluminium connectors, so that the aluminium conductor can be taken direct to the box and a bi-metallic connector on the line avoided.

GUARDING.

In order to comply with the regulations, guards must be fitted at all public road, canal and railway crossings. At road and canal crossings the best method is to duplicate the insulators, fit bridles extending 4 ft. from the insulator and of the same material as the conductor, and erect an earthing bracket. Fig. 18 shows such an arrangement. Clamp the bridles by two Crosby clips at each end and tape the bridle and conductor to prevent damage by the clips. Connect the earthing wire to the bracket by means of a flag washer and a separate earthing bolt.

Guards for Railway Crossings.

For railway crossings the companies usually ask for the span to be reduced as much as possible and for duplicate insulators and duplicate conductors to be fitted. Bind the duplicate conductor to the main conductor every 5 ft., the bind extending over 1½ in. Erecting the duplicate conductor is an expensive operation as it is not possible to drop the conductor down on to the railway to make the binds. The writer recommends that the main conductor be pulled up to tension and the position of the duplicate marked on it. Then slacken out until the marked portion is clear of the railway, let it down to the ground, clamping a stop on the conductor at the adjacent pole and bind on the duplicate conductor. Lift up on to the running blocks again, pull into position and tension up. Clamp off the ends of the duplicates as you would a bridle and the guard is complete.

Guarding is also compulsory where lines run alongside and within 50 ft. of a public road. For these conditions the insulators may be duplicated and bridles fitted, or else an earthing bracket erected.

Crossing Post Office Lines.

Where Post Office lines are crossed the Postmaster-General stipulates that special precautions are to be taken and has issued regulations accordingly. The guard usually takes the form of a cradle or mat carried on four independent poles. In order to obtain a good appearance and avoid excessive sag on the cross lacings of the cradle, the writer uses lacings of $\frac{3}{8}$ in. galvanised gas tubing instead of stranded or solid wire.

Bird Guards.

A considerable amount of work has to be done before the line can be considered as completed. Unless some form of sloping crossarm, such as that used for the Norwich Rural Demonstration Scheme illustrated in Fig. 20, is adopted which will prevent bird faults, bird guards must be fitted to the crossarms. Semaphite guards will be found particularly useful for this purpose as, in addition to being available in various sizes to suit the cross-arms, they can be supplied in sheets which can be cut and bent on site to suit awkward shapes, such as switchgear frameworks.

Finishing Off.

After the bird guards have been erected, screw on the danger notice and number plate about 10 to 11 feet above ground level. Use fibre washers on top of enamelled plates to prevent damage and also behind danger notices, so as to keep them clear of the pole and prevent creosote from draining over and spoiling the appearance. The last work to be done on the pole is to put on the anti-climbing guard, which should consist of seven turns of barbed wire spaced between 8 ft. and 10 ft. above ground.

Final Check.

It now only remains to walk through the line carefully inspecting every detail and checking each pole against the draft for the permanent records which should have been compiled as the work proceeded; make sure that all scrap ends of wire, bolts, etc. have been removed; see that fences and hedges have been satisfactorily repaired and pressure test the line. In the case of very short lines up to 11,000 volts, the pressure test may be an alternating current one carried out by means of a testing transformer, but most testing nowadays is done by means of one of the three or four direct current testing sets on the market. A detailed description of the sets and how to make the test is beyond the scope of this article.

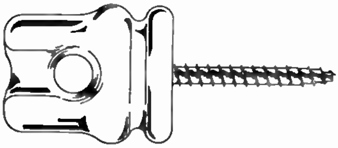


Fig. 36.—"Wonpeace" Service Insulator for Screwing into Pole or Wall and Suitable for Three or Four Services. (*Johnson and Phillips, Ltd.*)

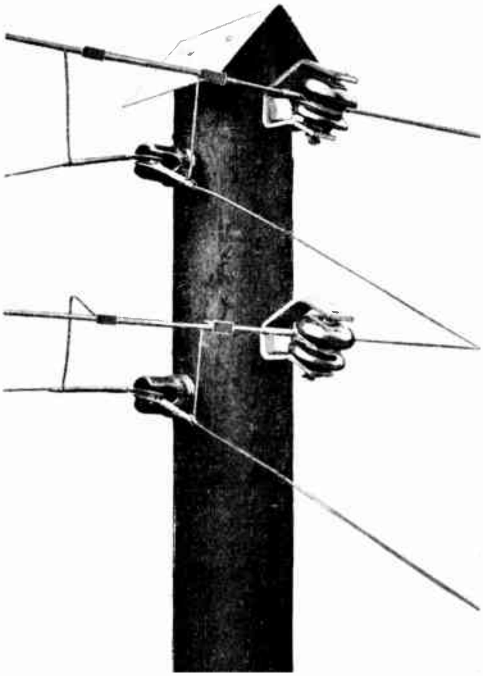


Fig. 35.—View of L.T. Pole Top, Using "Juno" Brackets for the Line Conductors. The two-wire services are shown terminated on "Wonpeace" insulators.

STEEL TOWER LINES.

Much of the work already described for E.H.T. wood pole lines will apply to steel tower lines and the chief differences are emphasised in the following remarks and illustrations.

Surveying.

The survey work must be extremely accurate as it is not possible to check the alignment until the towers are erected, and should any fault be found it will be extremely difficult and, in some cases, impossible, to remove and replant the stubs. When the tower peg is planted, two additional pegs are placed about 20 feet fore and aft, so as to provide a local sighting line. This enables the stub positions to be marked out later square to the line without further use of the theodolite.

Excavation and Stubsetting.

The stubs should next be assembled adjacent to the pegs. Mark out the hole or holes by means of a wooden templet and arrange to disturb the ground as little as possible. Owing to the large excavation volumes considerable money can be saved if this work is done accurately. Fig. 21 illustrates this point and it will be noticed that the surveyor's centre peg has not been disturbed. This will enable the original accuracy of the setting out to be retained.

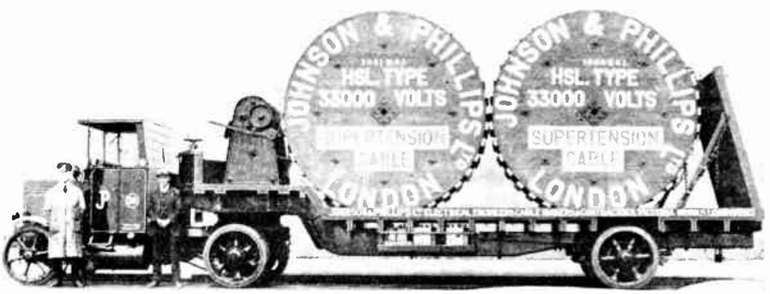


Fig. 37.—Modern Cable Lorry with Winch and Long Tailboard for Unloading Heavy Cable Drums.

Fig. 22 shows the method employed for placing the stub, which may weigh six hundredweights or more, in the hole already illustrated. Before lowering the stub a layer of concrete is placed in each corner to prevent the edges of the grillage angles sinking into the ground when the tower and conductor loads are added later. When the stub is in position it has to be lined up and levelled. To do this, the four corners of the stub are now tied by ropes with turnbuckles to four timbers placed across the corners of the hole. A cord is run between the studs on the surveyor's three pegs and the stub moved until the centre marks on the stub horizontals are underneath the cord. The tower will thus be square to the line and in alignment. Level the stub now in both directions by using temporary bars fixed to the stub drillings and adjusting the turnbuckles, as in Fig. 23. Partially fill in and ram and lay any encasing concrete to protect the steelwork near the ground level. This is usually done for 2 ft. below and 6 in. above ground, as shown in Fig. 24.

Tower Erection.

Towers may be erected by two methods. In the first method they are assembled complete in a horizontal position and attached to two of the stub angles by means of bolts or hinges. They are then pulled up by means of a falling or standing gin pole, generally similar to the description given for wood poles.

The writer's experience shows that the second erection method is more economical and in addition it eliminates any possibility of over-stressing the tower or foundation which might occur with the first method. The alternative is to build the tower up piece by piece in a vertical direction. Fig. 25 illustrates a tower being erected in this way and shows the bottom crossarm being hauled up into position. All tower joints should be given a coating of thick paste, such as "Stablex," before bolting up so as to seal the joints against moisture and prevent rusting of hidden surfaces.

The conductor and other work on a steel tower line differs very little from that on a wood pole line, but Fig. 26 is of interest, as it shows the running blocks on a heavy angle tower. The position of the straining clamps has been marked off and they are being fixed prior to being attached to the straining insulators. Fig. 27 illustrates a section of the completed line.

L.T. DISTRIBUTION LINES.

Voltage.

The Electricity Commissioners have decided upon 400/230 volts alternating current at 50 cycles as the standard for L.T. public supply in this country. Most distribution work is carried out on the three-phase four-wire system with 230 volts from phase to neutral and 400 volts across the phases. A fifth wire of smaller section is sometimes erected for street lighting. Single phase two-wire lines are used whenever possible for short branch lines with little load, but provision should almost always be made for conversion to four-wire if found necessary at a later date.

Pressure Drop.

Pressure drop on L.T. overhead lines is an extremely important matter, as will be seen from Fig. 28, which shows the percentage voltage drop on three-phase four-wire lines when carrying various loads or currents a distance of 1,000 route yards. The diagram is based on a concentrated load at this distance. Should the load be evenly distributed along the route, instead of concentrated, the pressure drop would be half that given by the diagram. It will be noticed that the abscissa limit of the chart is 100 kVA. which, for the smallest conductor, gives a percentage voltage drop of approximately 65 per cent. This is, of course, impracticable, not only from voltage drop point of view, but also from the point of view of conductor heating. The limit has been set at 100 kVA. simply because it is a very convenient figure for fractionating.

The chart can be used for determining the voltage drop for any route length simply by multiplying the percentage voltage drop derived from the chart for the kVA. and conductor concerned, by the ratio of the actual route length in yards divided by 1,000.

Fig. 38.—LAYING CABLE BY MEANS OF DRUM WHEELS.

As the drum is moved along the cable is dropped into the trench. This method can only be used where there are no obstructions in the trench.

Obtaining Percentage Voltage Drop.

It is also possible to obtain percentage voltage drops accurately for quite small loads, as exemplified by the following:—

Suppose a load of 5 kVA. is to be transmitted 1,000 yards over a 0.075 sq. in. conductor. It an attempt be made to read this direct from the chart from the abscissa value of 5 kVA., it would be seen that the resulting accuracy would not be of a very high order. If, however, we read the voltage drop corresponding to, say, 50 kVA. and divide the value so obtained by 10, we get immediately the required voltage drop for 5 kVA. much more accurately. Alternatively, we could

Fig. 39.—Laying E.H.T. Cable in Trench, Using Rollers for Pulling Out.

take the voltage drop of 100 kVA. and divide by 20 to obtain it at 5 kVA.

It will, no doubt, be realised that the chart is reversible; that is to say, it is easy to ascertain what size of conductor should be used for a given voltage drop and kVA. load. In this case it is only necessary to trace horizontally to the right from the ordinate corresponding to the specified voltage drop, and vertically upwards from the abscissa corresponding to the specified kVA. load, when the intersection of the two lines will lie on one of the radial lines indicating conductor sizes, or between two of them; it then being a matter of practical economics to decide which conductor shall be used.

Conductors.

Conductors are invariably of hard drawn copper and they should be stranded in preference to solid, as this will make for easier erection, and it will not be necessary to pull up so tightly to obtain a good appearance. In view of the present rapid development of cooking and heating loads, the writer recommends 0.1 sq. in. section should be used. Very little will be gained by using a larger size and if 0.1 sq. in. is not sufficient, other routes should be developed so as to form a ring main, if possible. Smaller sizes, excepting for short spurs, will eventually lead to pressure drop difficulties. For the same reason the neutral should be the same sectional area as the phase wires. Table VII gives the mechanical and electrical characteristics of 0.05 and 0.1 sq. in. copper conductors; the impedances are for 12 in. vertical spacing, and the safe carrying currents are for a temperature rise of 54° F. (30° C.) in still air.

On account of voltage drop it will be very rare that a line can be worked up to the safe carrying currents stated.

Spans and Pole Sizes.

Long spans cannot be used on L.T. lines, as it is necessary to space poles at close intervals in order to take off services. In addition, routes are seldom straight,

TABLE VII.

Conductor Characteristics.

Size. Square Inches.	Stranding.	Overall Diameter. Inches.	Weight. Lbs. per 1,000 yards.	Breaking Load. Lbs.	Resistance. Ohms.	Impedance. Ohms.	Safe Carrying Currents. Amperes.
					Per 1,000 yards.		
0.05	3/.147"	0.317	601	2,914	0.4943	0.569	120
0.1	7/.136"	0.408	1,196	5,872	0.2469	0.362	200

Fig. 40.—" FLAKING " CABLE IN THE FORM OF A FIGURE EIGHT.
Keep the radius of all bends as large as possible.

poles have to be erected at branch roads and Post Office wires will be encountered, and these considerations render it difficult to employ long spans. The popular span is 150 ft. and the regulations allow a sag of 1 ft. with either of the conductor sizes being considered. However, if the conductors are tensioned to this small sag, considerable difficulties will be experienced with staying, poles bending and foundations giving, unless these items are strengthened up to correspond and this will be expensive. The writer suggests that 2 ft. to 2 ft. 6 in. sag be adopted for both sizes of conductors.

Single type poles only are employed, mostly of creosoted red fir. The overall lengths and diameters at 5 ft. from the butt are as follows :—

TABLE VIII.
L.T. pole sizes for 150 ft. spans.

Conductors.	Pole Size.
0.05 square inch four-wire ..	28′ × 7½″
0.05 square inch five-wire ..	30′ × 8″
0.1 square inch four-wire ..	28′ × 7¾″
0.1 square inch five-wire ..	30′ × 8¼″

These sizes are based on 17 ft. minimum ground clearance and a 0.025 sq. in. switch wire for the fifth wire. At road crossings, 19 ft. clearance is necessary and the pole length should be increased by 2 ft. and the diameter by ¼ in. The poles should be planted 5 ft. deep in the ground and foundation blocks are not required, assuming normal ground.

Tubular steel poles are sometimes adopted instead of wood, but as their cost is higher their use is limited. The diameters and thicknesses will vary with the particular manufacturer. If steel poles are used, a continuous earth wire must be erected, or else an earth plate installed at each pole.

Stays.

The stays for angle and terminal poles should comprise an 8 ft. by ⅝ in. stay rod with 4 ft. by 8 in. by 4 in. creosoted stay block and 7/9 S.W.G. 40-ton quality steel stay wire. One stay of this size should be used for terminals on the 0.05 sq. in. four-wire line and two for the 0.1 sq. in. One stay of a larger size could be used on the 0.1 sq. in. line, but the erecting engineer will find that there will be considerable bending in the pole. It is frequently impossible to erect a stay at angle positions and if the deviation is small, say, of the order of 10°, an 11 in. diameter pole should be used instead.

At larger angles struts or flying stays should be used if ordinary stays are not suitable

Excepting on steel pole lines, all stays must have an insulator in the stay wire, as shown in Fig. 30. See that this insulator is of the interlinked type, with a mechanical strength at least equal to that of the stay itself.

Pole Fittings.

Fig. 41.—DRAWING CABLE INTO DUCT.
See that the cable leaves the top of the drum and passes into the duct beneath the drum so as to avoid a reverse bend.

The insulators for carrying the conductors should be of brown glaze shackle pattern fixed in "D" brackets bolted to the pole. One of the latest types of bracket is that patented by Johnson and Phillips and shown in Fig. 29, for which the following claims are made :—

(*a*) The conductor weight is taken by the porcelain and not by the binding wire.

(*b*) The insulator can often be used as a roller for running out conductors, thus speeding up and cheapening erection and avoiding damage to the conductor.

(*c*) Only one type of insulator is necessary throughout a network.

(*d*) All poles, straight-line, angle, T and terminal, are drilled alike, therefore amendments to the lay-out or future alterations are easily made.

(*e*) The bracket is reversible so as to suit left or right-handed deviations.

(*f*) A spanner is not required for holding the pole bolt-head, which locks inside the bracket.

(*g*) The design is much stronger than pin insulators or swan-necks.

(*h*) The conductor is approximately on the same centre line as the pole bolt, thus eliminating undesirable bending stresses.

The ultimate strength of this bracket is over 6,000 lbs. in a horizontal direction and averages 1,090 lbs. in a vertical direction. The corresponding elastic limits average 3,200 and 900 lbs. respectively. As the horizontal load on a 0.1 sq. in. ice covered conductor on 150 ft. span is only 78 lbs. and the vertical load 81 lbs., the safety factor is extremely satisfactory. An alternative form of this bracket is shown in Fig. 31, and it will be seen that the insulator can be fixed vertically for straining positions, or inclined to the right or left for straight line or small angles.

Erection of an L.T. Line.

The erection of an L.T. line is much simpler than that of an E.H.T. one. The methods, however will be generally similar, excepting in certain details mentioned hereafter.

In the first place, it will be unnecessary to carry out any surveying or construct a profile. Occasionally a few levels will be required for positions where Post Office circuits have to be crossed.

When ordering the poles it will not be necessary to have them numbered as except for size all poles will be similar. Make sure, however, that the length is clearly stamped on the butt of all poles longer than normal.

When the poles arrive at the railway station the carting will be a simple matter as the weights to be handled will only be of the order of six hundredweights.

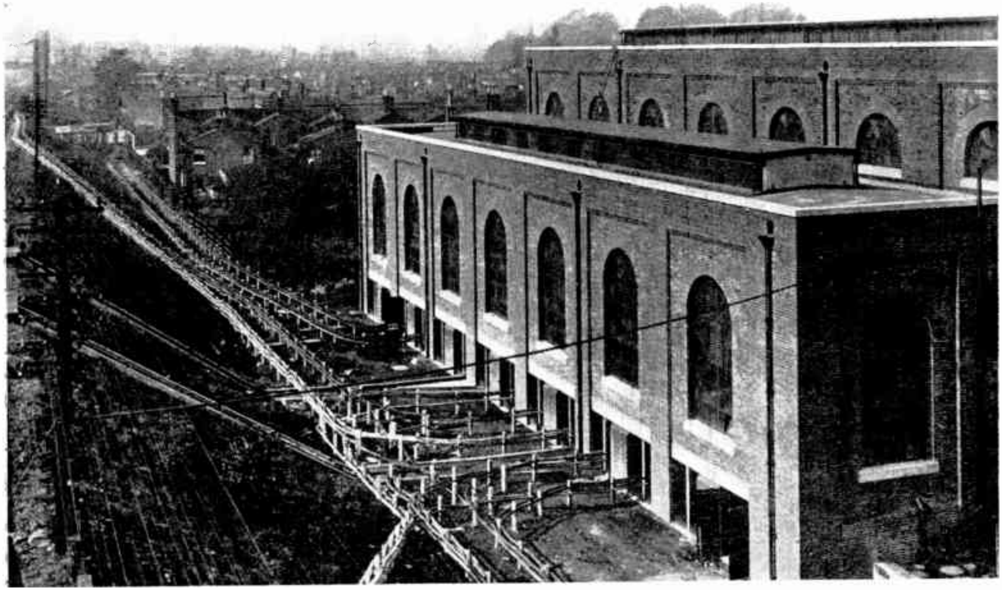


Fig. 42.—E.H.T. CABLES ERECTED ON REINFORCED CONCRETE POSTS FOR RAILWAY ELECTRIFICATION. (*Johnson and Phillips, Ltd.*)

Arrange for each pole to be unloaded from the lorry at its correct position and this will easily be arranged if the design is such that all poles are drilled alike.

Using a Petrol Borer.

If the holes are excavated by hand, mark out the hole so that the pole can bear directly against two of its sides. Step the hole so as to disturb as little ground as possible. If a petrol driven boring machine is available and the ground is not rocky, considerable economies can be effected by its use, as the time occupied in moving

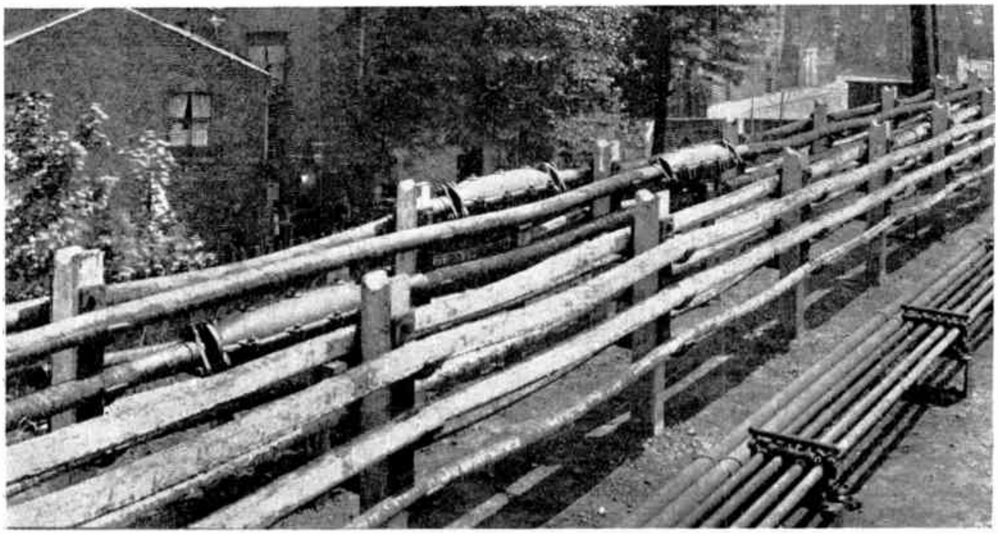


Fig. 43.—METHOD OF LAYING CABLES ALONGSIDE RAILWAY.
The concrete posts are spaced 4 feet to 5 feet apart. (*Johnson and Phillips, Ltd.*)

from pole to pole is relatively short. Two to three men can easily move the borer about on roadside L.T. work. The drill will go through most types of surfaces except, of course, flags, concrete, setts or the like, which should removed by hand.

Erecting the Pole.

On account of the light weights and short lengths, L.T. poles are erected by a different method to E.H.T. poles. Figures 32 and 33 are almost self-explanatory. Lift the pole on to the handcart, back it over the hole and tip up the truck so that the pole butt is against the board in the hole. Take the weight by means of a pole fork and remove the handcart. Two men on the fork and two men steadying the pole, as in Fig. 33, will be able to push it up into position.

Running Out the Conductor.

The last two illustrations show a pole inside a field, but generally L.T. poles will be planted along footpaths or roadsides. This will enable the conductor to be run out, in cases where there are no Post Office crossings in the way, by mounting the drum on a lorry and driving along the route. As the lorry moves forward the conductor is lifted to the top of the poles and kept under slight tension. Running blocks should be used if possible, as for E.H.T. conductors, but considerable saving can be effected by using the porcelain shown in Fig. 30 as a roller. Alternatively to this, the insulator bolt, being inclined, can be used and will enable tensioning and sagging to be carried out more easily and with greater accuracy than if no form of roller be employed. If blocks or rollers are not used, the conductors will be damaged by dragging them over the brackets.

At straining points, bind the conductors for a length of 6 in. to 8 in. with No. 12 or No. 14 S.W.G. soft copper wire and finish off at terminals with a neat tail, which will be available for a jumper should the line be extended. As an alternative to binding off at straining points, two galvanised wire rope clips can be used on each conductor.

Guard Wire.

Where L.T. lines cross under Post Office wires it is necessary to erect above the power conductors a guard wire. Fix this wire to insulators at each end and bond it to the neutral conductor. The guard wire is generally 7/14 S.W.G. steel strand. Where L.T. lines cross over Post Office wires put in a span of P.B.J. insulated conductors, using a straining type pole at each end. The neutral wire need not be P.B.J., but can remain bare. The P.B.J. conductor should receive the Post Office approval and samples will generally be requested. P.B.J. conductors are of plain hard drawn copper, insulated with impregnated paper or cambric and protected by a cotton covering impregnated with a red lead compound. This, in turn, is covered overall by a cotton braiding also saturated with red lead. The red lead compound—hardened through oxidisation under the action of the atmosphere—provides a highly resistant and reliable covering which, though its insulating value is not large, is sufficient to prevent danger to telephone operators should a telephone wire come into accidental contact with it. P.B.J. can be finished in yellow, green, red, chocolate or blue colour and is paraffin waxed overall.

Use of Safety Belt.

Danger notices, number plates and anti-climbing guards are not usually required on L.T. lines, but Fig. 34 shows an operation which will often be necessary. A transformer platform is being fixed to an E.H.T. pole, from which a L.T. line will commence. Holes are also being drilled for the switchgear to control the transformer. This illustration brings out a point not previously mentioned; it is most important that men working up a pole have and use a reliable and well-designed safety belt. Many men have been saved a serious fall of 20 to 30 feet by their safety belts, and a very strict rule should be enforced.

Services.

Service wires must be made off on to insulators at a pole, and it is not permissible to take them straight on to the distributors at various points in the spans. For the phase wires, P.B.J. conductors are generally used, and for the neutral,

Fig. 44.—Laying E.H.T. Cable Across the River Thames near Henley. (*Johnson and Phillips, Ltd.*)

bare copper. Standardise a 0.0225 sq. in. (7/.064 in.) section and use this stranding as it will mean that much less tension will be necessary to get a good appearance. With solid-service wires the engineer will find that considerably more tension is required to straighten them out. With long services the tensions are likely to cause difficulty with the poles pulling over, and services should therefore be arranged to balance each other as far as possible. If the economics of the scheme will stand it, the writer recommends using poles 1 in. larger in diameter than the minimum permissible and this will prove of great value when services are added.

"Wonpeace" Service Insulator.

The conductors can be made off on to the pole by adding shackle straps, insulators, bolts and nuts to the distributor fittings. Similar equipment with the addition of a wall spike or rag bolt will be necessary for the house end of the service. Many small variations can be made using distance tubes and long bolts, but one of the most useful designs is that developed by Johnson and Phillips and illustrated in Figs. 35 and 36. It is known as the "Wonpeace" service insulator, and all loose metalwork, bolts, nuts and washers are eliminated. This service insulator consists of a brown glazed, best quality, high strength porcelain, suitably shedded and fitted with a galvanised coach screw for pole or wall fixing, or alternatively fitted with a steel stud for bracket fixing. The advantages of the "Wonpeace" insulator are :—

(*a*) It is cheaper than any other method.

(*b*) No separate ironwork, screws or bolts, etc. are required.

(*c*) Three or four services can easily be taken from one fitting due to the large diameter hole. This is not possible with shackle insulators.

(*d*) It is not necessary to disturb the existing line fittings in order to add services.

(*e*) The coach screw is gimlet-pointed for easy erection.

(*f*) Large creepage surface.

(*g*) Large savings in assembly and erection costs.

(*h*) Wires can be erected immediately, no waiting for cemented ragbolts to set.

The "Wonpeace" insulator is fixed to a pole by drilling a 1½ in. by ¼ in.

diameter hole and screwing home by hand, a tool not being necessary for this purpose.

"Wonpeace" insulators may be cemented into walls, but the writer recommends Rawlplug fixing, which not only saves considerable time and is extremely strong, but has the advantage that service wires can be strung immediately. With cement fixings a second visit must be made for erecting the wires, owing to the necessity for the cement to set. "Wonpeace" insulators save this travelling time.

The stud pattern is supplied with a 2 in. diameter by $\frac{1}{8}$ in. thick Semaphite washer to act as a cushion.

Tests on "Wonpeace" Insulators.

Tests on the insulators give the following average results for mechanical strength :—

Direct pull in line with screw or stud—900 lbs.

Lateral pull at right-angles—572 lbs.

As the tension of the average service wire is between 10 and 40 lbs., it will be seen that the factor of safety is a very high one.

Attach the service conductors to the distributors by means of small brass or gunmetal clamp connectors. At the other end attach them to the service cables by small tubular connectors. Carefully tape up and paint the joint at this position so as to prevent moisture entering the cable. A tubular connector will make this job easier and of better appearance.

To conclude this description of the practical side of overhead line work, the author wishes to thank Messrs. Johnson and Phillips, Limited, for facilities to take photographs and permission to publish certain of their tables.

UNDERGROUND POWER CABLES.

Type of Cable.

Cables may be broadly classified according to the conditions under which they will be laid, as follows:—

(*a*) Cable for laying direct in the ground.

(*b*) Cables for drawing into ducts or pipes.

(*c*) Cables for laying in troughing.

(*d*) Cables for laying on posts.

(*e*) Cables for laying under water.

The majority of cables come under the first grouping and are either armoured with steel tapes or iron wires, with a hessian serving overall. There is a tendency at the present time to use unarmoured cables laid direct, on the score of cheapness, the lead sheathing being protected from chemical damage by waterproofed tapes with or without a hessian serving. The saving is comparatively small and extreme care is necessary with the trenching and filling in, in order to avoid damage to the cable. Some supply authorities use steel tape armouring on L.T. cables and steel wire armouring on E.H.T. cables, and this is an excellent idea as it prevents accidentally cutting the wrong cable when putting on services, should there be two cables in one trench. Wire armouring should be used whenever there is any chance of ground subsidences.

Fig. 45.—JOHNSON AND PHILLIPS' SUBMARINE CABLES REMOVED FROM WEYMOUTH HARBOUR TO NEW POSITION ABOVE HIGH WATER LEVEL AFTER 25 YEARS IN SALINE MUD.

The cables, armouring and serving were found to be in perfect condition.

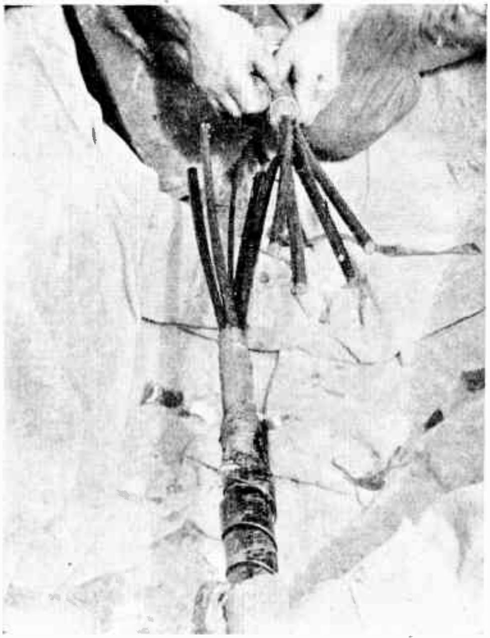


Fig. 46.—L.T. STRAIGHT-THROUGH CABLE JOINT—FIRST STAGE.
Showing armouring and lead sheath cut back.

Fig. 47.—L.T. STRAIGHT-THROUGH CABLE JOINT—SECOND STAGE.
Showing core taped up.

Fig. 48.—L.T. STRAIGHT-THROUGH CABLE JOINT—THIRD STAGE.
Showing taping of cores completed, cores cut to length and ferrules in position.

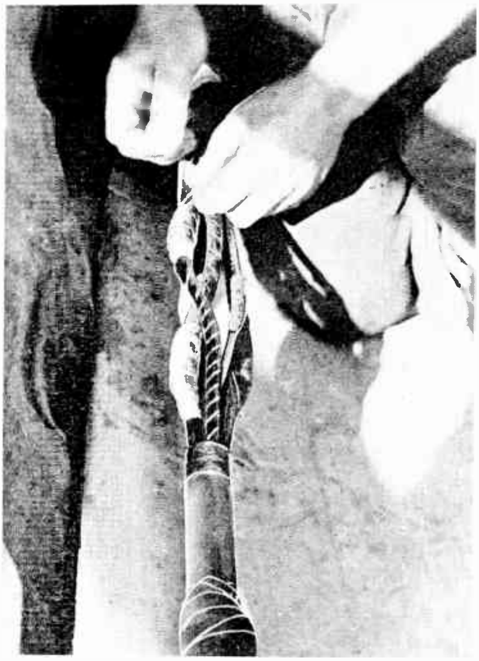


Fig. 49.—L.T. STRAIGHT-THROUGH CABLE JOINT—FOURTH STAGE.
Showing linen tape being applied to joint ferrules.

Cables Laid Direct in the Ground.

When cables are laid direct in the ground, some form of marker is usually laid 4 in. above so that future excavators are warned. Markers may be creosoted wood boards, preferably 2 in. thick and in lengths of 10 to 20 feet, interlocked tiles 9 in. long, or interlocked reinforced concrete slabs 3 ft. long. Creosoted wood boards have the advantages of easy handling, fewer joints and that they are not likely to be disturbed by other excavators, but their life is sometimes comparatively short. Tiles are easily removed and, inadvertently, may not be replaced when trenches are opened by other authorities. Concrete markers have the disadvantage of heavy weight, but are everlasting and not likely to be disturbed. Tiles and concrete slabs can be stamped "Electricity" or other suitable wording.

Cables for Drawing into Ducts.

Cables for drawing into ducts are generally plain lead covered. Sometimes they are given a serving of hessian for protection. There is comparatively little of this class of cable laying, but it sometimes happens that when a cable is being laid direct, a duct is also laid in anticipation of an additional cable later. Cables are often pulled into ducts or pipes for crossing roads or railways, but in such cases they form part of the main cable run and are armoured, as it would be expensive to manufacture and joint up a short piece of cable, lead covered only.

Cables for Laying Solid in Troughing.

Cables for laying solid in troughing are not used for ordinary pressures unless the ground is chemically active. This type of cable laying is expensive and a modern development for these conditions is to use a paper insulated, lead covered, bitumen sheathed, armoured, served and specially compounded cable, and lay it direct in the ground. The bitumen sheathing protects the cable from chemical action and has been proved quite satisfactory. The cost is considerably less than when using troughing, and the laying is much simpler and quicker.

Cables for Laying on Posts.

Cables for laying on posts are mostly used for railway work where there is little risk of wilful damage. They may be either lead covered and armoured or lead covered and hessian served. On account of the vibration to which these cables are subjected, the lead sheathing should consist of a special alloy.

Under Water Laying.

Cables for laying under water are always lead covered and armoured with two complete layers of galvanised wires for mechanical strength. Specially waterproofed hessian tapes are placed under, between and over the armouring wires.

Choosing Correct Size of Cable.

The choice of the correct size of cable is a lengthy matter involving pressure drop, maximum current carrying capacity, prime cost, annual losses, cost of current and estimated future demand, and is beyond the scope of this article. The conductor cores may be either round or sector. Round conductors are slightly easier to joint than sector shaped, but the latter give a smaller diameter cable and are somewhat cheaper. Table IX, giving the impedances for underground cables up to 11,000 volts, will be useful for voltage drop calculations.

Excavation.

When deciding on a cable run it is important that careful consideration be given to the excavation and the surface reinstatement which will be encountered. The excavation and reinstatement costs are big items and are, for small cables, even greater than the cost of the cable itself. In the case of L.T. cables a choice will seldom be possible, as the route will generally be fixed by the services required. For E.H.T. cables the shortest route should be considered first, but it will often be found that, by using back streets and a longer route, the total cost will be reduced, due to easier excavations, cheaper reinstatement, fewer obstructions such as gas, water and Post Office mains, less traffic and fewer road crossings. Whenever possible, cables should be laid in the pathways or in the grass verge.

TABLE IX.

RESISTANCE, REACTANCE AND IMPEDANCE OF MULTICORE CABLES AT 50 CYCLES AND 15° C. (*Johnson and Phillips, Ltd.*)

Standard Sizes. Nominal Area. Square Inches.	No. and Diameter of Wires Comprising Standard Conductor. No./inch.	Thickness of Dielectric. Inches.	Standard Resistance inc. 2% for Cabling and 2% Tolerance, per mile per core. Ohms.	Inductance inc. 2% for Cabling, per mile per core. *Millihenrys.	Circular Conductors.		Sector Conductors.	
					Reactance inc. 2% for Cabling, per mile per core. Ohms.	Impedance inc. 2% for Cabling, per mile per core. Ohms.	Reactance inc. 2% for Cabling, per mile per core. Ohms.	Impedance inc. 2% for Cabling, per mile per core. Ohms.
660 VOLTS.								
0.007	7/.036	0.080	6.271	0.4911	0.15428	6.272	0.14194	6.272
0.01	7/.044	0.080	4.197	0.4646	0.14596	4.199	0.13428	4.199
0.0145	7/.052	0.080	3.005	0.4451	0.13983	3.008	0.12864	3.007
0.0225	7/.064	0.080	1.985	0.4235	0.13305	1.989	0.12241	1.988
0.03	19/.044	0.080	1.549	0.4110	0.12912	1.554	0.11879	1.553
0.04	19/.052	0.080	1.109	0.3972	0.12478	1.116	0.11480	1.115
0.06	19/.064	0.080	0.7323	0.3824	0.12013	0.7419	0.11052	0.7406
0.075	19/.072	0.080	0.5786	0.3751	0.11784	0.5905	0.10841	0.5887
0.10	19/.083	0.080	0.4354	0.3672	0.11536	0.4504	0.10613	0.4481
0.12	37/.064	0.080	0.3761	0.3632	0.11410	0.3930	0.10497	0.3904
0.15	37/.072	0.080	0.2972	0.3575	0.11231	0.3176	0.10333	0.3147
0.20	37/.083	0.080	0.2237	0.3516	0.11046	0.2495	0.10162	0.2457
0.25	37/.093	0.090	0.1782	0.3517	0.11049	0.2096	0.10165	0.2051
0.30	37/.103	0.090	0.1452	0.3479	0.10930	0.1818	0.10056	0.1766
0.40	61/.093	0.100	0.1082	0.3463	0.10879	0.1534	0.10009	0.1474
0.50	61/.103	0.100	0.08814	0.3429	0.10773	0.1392	0.09911	0.1327
3,300 VOLTS.								
0.0145	7/.052	0.14	3.005	0.5193	0.16314	3.009	0.15009	3.008
0.0225	7/.064	0.14	1.985	0.4888	0.15356	1.991	0.14128	1.990
0.04	19/.052	0.14	1.109	0.4505	0.14153	1.118	0.13021	1.117
0.06	19/.064	0.14	0.7323	0.4283	0.13455	0.7446	0.12379	0.7427
0.075	19/.072	0.14	0.5786	0.4171	0.13104	0.5932	0.12056	0.5910
0.10	19/.083	0.14	0.4354	0.4046	0.12711	0.4536	0.11694	0.4508
0.12	37/.064	0.14	0.3761	0.3984	0.12516	0.3965	0.11515	0.3934
0.15	37/.072	0.14	0.2972	0.3897	0.12243	0.3215	0.11264	0.3178
0.20	37/.083	0.14	0.2237	0.3802	0.11944	0.2536	0.10988	0.2492
0.25	37/.093	0.14	0.1782	0.3731	0.11721	0.2133	0.10783	0.2083
6,600 VOLTS.								
0.0145	7/.052	0.20	3.005	0.5799	0.18218	3.009	0.16761	3.009
0.0225	7/.064	0.20	1.985	0.5433	0.17068	1.993	0.15703	1.991
0.03	19/.044	0.20	1.549	0.5212	0.16374	1.558	0.15064	1.556
0.04	19/.052	0.20	1.109	0.4963	0.15592	1.119	0.14345	1.119
0.06	19/.064	0.20	0.7323	0.4685	0.14718	0.7469	0.13541	0.7447
0.075	19/.072	0.20	0.5786	0.4541	0.14266	0.5960	0.13125	0.5932
0.10	19/.083	0.20	0.4354	0.4383	0.13770	0.4567	0.12668	0.4536
0.12	37/.064	0.20	0.3761	0.4303	0.13518	0.3997	0.12437	0.3962
0.15	37/.072	0.20	0.2972	0.4189	0.13160	0.3250	0.12107	0.3207
0.20	37/.083	0.20	0.2237	0.4063	0.12764	0.2575	0.11743	0.2526
0.25	37/.093	0.20	0.1782	0.3971	0.12475	0.2175	0.11477	0.2119
11,000 VOLTS.								
0.0225	7/.064	0.3	1.985	0.6177	0.19406	1.995	0.17854	1.993
0.03	19/.044	0.3	1.549	0.5912	0.18574	1.561	0.17088	1.558
0.04	19/.052	0.3	1.109	0.5609	0.17621	1.123	0.16211	1.119
0.06	19/.064	0.3	0.7323	0.5262	0.16531	0.7508	0.15209	0.7477
0.075	19/.072	0.3	0.5786	0.5081	0.15962	0.6002	0.14685	0.5969
0.10	19/.083	0.3	0.4354	0.4878	0.15325	0.4616	0.14099	0.4577
0.12	37/.064	0.3	0.3761	0.4774	0.14998	0.4050	0.13798	0.4005
0.15	37/.072	0.3	0.2972	0.4624	0.14527	0.3308	0.13365	0.3258
0.20	37/.083	0.3	0.2237	0.4457	0.14002	0.2638	0.12882	0.2581
0.25	37/.093	0.3	0.1782	0.4336	0.13622	0.2244	0.12532	0.2178

* For sector cables, multiply these figures by 0.92.

Fig. 50. L.T. Straight-through Cable Joint—Fifth Stage.

Showing lead sleeve in position and plumbed on to the sheath.

Depths at which Cable should be Laid.

It cannot be said that standard depths exist at which cables should be laid, but the minimum depths consistent with safety are 30 in. in roadways, 24 in. in grassland and 12 in. in footpaths and grass verge. It will frequently be necessary to increase these depths on account of obstructions. E.H.T. cables in pathways should preferably be laid 6 in. deeper for greater safety and in order to avoid confusion with L.T. cables. Under tramways and railways, L.T. and E.H.T. cables should be laid 48 in. deep and be drawn into iron pipes.

What to do before Beginning Excavation.

Before the excavation is begun, mark out the edges of the trench, whenever the ground surface permits, so as to save digging and reinstatement costs and to obtain a good appearance when the surface has been reinstated. To do this, chalk a 30 ft. length of cord, stretch it tightly along the ground and twang it. The cord will then leave a straight chalk line where the trench has to be cut. Remove the surface of the ground and carefully put it on one side so as to be available for finishing off the backfilling. If the surface is grass, cut it into sods and roll them. If the surface is flagged, great care should be exercised so as to avoid breakages or flaking and the flags should be set aside opposite their correct positions.

Excepting where, owing to the nature of the route, it is certain that obstructions will not be encountered, take out trial holes a few yards in advance of the excavation gang. If this is not done, portions of the trench may have to be filled in where a diversion is found necessary.

Sumps for Bailing Out.

Keep the edge of the trench quite clear of excavated material and arrange the latter so that it prevents surface water from running into the trench. When the trench is likely to be open during rainy weather, dig small sumps about 10 in. deep at intervals for baling or pumping out. Support any pipes which are exposed by means of chains or ropes from timbers laid across the trench, and, if necessary, consult the owner's representative.

Timbering.

Trenches in footpaths, at the shallow depths generally used, will not require timbering, but caution should be exercised where trenches run close to the footings of old walls or houses. Accidents and expensive damage have resulted in cases where temporary support has not been given. Trenches alongside roadways should always be timbered if it is not possible to keep traffic well away from the edge. Timbering, however, not only costs money but delays the cable laying and it should therefore be avoided if at all possible with safety.

When sufficient length of trench has been opened to take a drum of cable, see that the bottom is level and reasonably smooth and when the ground is of a stony or rocky nature put in a layer of riddled earth to form a bed for the cable.

Filling Up the Trench.

When the cable has been laid, put in more riddled earth and gradually fill up the trench. See that the ground is thoroughly punned while this is going on and finish off by replacing the surface materials. When not likely to cause accidents, leave a slight crown on the trench so as to allow for settlement. The ground should be permanently reinstated about a fortnight after filling in.

Laying Cables Direct.

Cables can be manufactured in lengths greater than those which can be conveniently handled on site. The best length will depend on the weight of the cable, the lay-out of the route and the number of obstructions, such as pipes and services. Usual lengths range from 250 to 440 yards and the writer recommends a maximum gross weight of about three tons. Cables will generally be delivered to site by the manufacturer's lorry, and unloading is then a simple operation as the lorry will be equipped specially to deal with this task. Fig. 37 shows one of a fleet of six and eight-wheelers belonging to Johnson and Phillips, and capable of handling with ease the largest and heaviest drums in use. These lorries are fitted with a long, heavy tailboard which can be used as a ramp and with a winch and wire rope for handling the drums.

Unloading.

If no special equipment exists for unloading, build up a ramp behind the lorry of stout timber and roll the drum slowly down by means of wire ropes. Arrange a heap of soil for the drum to land on and do not unload facing down a hill. Unload the drum as near as possible to where it will be used, and turn it so that it is held by a kerb if available, as boys have been known to remove chocks and set drums rolling.

Methods of Laying Cables Direct in the Ground.

Two methods are available for laying cables direct in the ground. In the first method, which is illustrated in Fig. 38, mount the cable drum on a pair of drum wheels and move them along the route, paying out the cable. This method is very quick and about a dozen men only will be required. It is only suitable, however, when the trench is absolutely free of obstructions and there are no side roads. It cannot therefore often be used.

In the second method, which is the more general, the drum is mounted on a pair of drum jacks and the cable is drawn off by hand. When rolling the drum into position take care to roll in the same direction as that marked on the drum, or else the cable will loosen, sag and possibly get damaged. Mount the drum on the two jacks supported on timbers to spread the load and see that the drum spindle is level. If this is not done the drum will work to one side, with a risk of overturning. Place capable rollers in the trench 15 ft. to 25 ft. apart, as shown in Fig. 39, and station a man between each roller. Pay out the cable, passing it from man to man and under any obstructions which may exist. Keep a brake on the drum by means of a plank to avoid over-running.

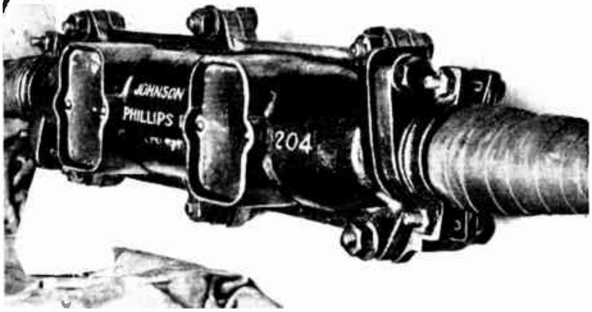


Fig. 51.—L.T. Straight-through Cable Joint. Complete with C.I. box filled and armour grips bolted on.

This method of laying a cable direct in the ground requires from 40 to 50 men, depending on the weight and length of the cable. If rollers are not available the cable should be drawn off the drum and carried by men spaced every 12 ft. to 20 ft. When the drum is empty lay the cable into the trench, starting at one end and moving the men forward, so as to take up the slack.

Flaking a Cable.

Sometimes it is not possible to complete the laying of a cable length which has been taken off a drum. In such a case set out the remaining cable in the form of a figure eight, as shown in Fig. 40, and as large as possible. Make each succeeding layer of cable slightly larger than the last. Occasionally, owing to difficult obstructions, it is desirable to mount the drum in the middle of the length of trench, instead of at one end, and pull half the cable each way. Before the second half of the cable can be laid it will be necessary to remove it from the drum. If space will allow, walk the men away with the cable so that it forms a long "U," and, if not, lay it out in a figure eight as above. This operation is called flaking a cable and requires careful watching to prevent the cable being bent too sharply. As regards the radius of any bends, the larger the better, but a minimum of twenty times the diameter of the cable is the general rule.

What to Do When Cable has been Laid.

When the cable has been laid in the trench, straighten it up and take records of its depth and distance from buildings, kerbs or other tying-in points. In crowded positions and where deviations are made to avoid obstructions, make sketches so as to enable the cable to be located easily should faults occur. When laying L.T. and E.H.T. cables in one trench, lay the L.T. nearest the houses so as to avoid crossing the E.H.T. cable with every service. Do not lay cables during very cold weather as the impregnating oil becomes stiff and the cable is difficult to handle and likely to get damaged.

Drawing into Ducts, etc.

When cables have to be drawn into ducts or pipes, the drum lengths are usually of the order of 400 feet. If the ducts were not laid with a wire through, it is necessary to push rods through, followed by a light rope. Pass a closely fitting mandril from end to end to ascertain that the duct is clean and free from obstructions, and then draw in the heavy rope for pulling the cable. Fig. 41 shows the drum in position, and it will be noticed that the cable comes from the top of the drum and passes into the ducts underneath the drum. The bending, therefore, is all in one direction. For attaching the cable to the pulling rope, the usual arrangement is to use the well-known stocking grip, unless the cable is a heavy one, when the rope should be attached to the cable cores themselves. If this is done, the cores must be sweated up solid and the cable end sealed up, so as to prevent damage by moisture. Avoid this method wherever possible. When pulling the cable in, coat it liberally with petroleum jelly.

Cables in Troughing.

Very little need be said about laying cables in troughing, because, as already mentioned, this method is seldom used. The troughs usually consist of rectangular, or U-shaped, stoneware, although wood is sometimes used, but cannot be recommended. Allow a clearance around the cable of not less than $\frac{1}{2}$ in. when deciding the size of the trough. Immediately before laying the cable sweep out the trough and place in the stoneware bridge pieces every 18 in., set in bitumen. When the cable has been laid, fill in solid with hot bitumen or pitch. Finally, top up heavily and, while soft, put on the covers.

Cables on Concrete Posts.

Figs. 42 and 43 show a large number of cables erected by Johnson and Phillips on reinforced concrete posts for the electrification of an important railway in this country. The posts are spaced 4 ft. to 5 ft. apart and the methods of laying are generally similar to those for laying a cable direct. It is frequently possible, however, to mount the drum on a railway truck and pay out the cable as the truck is moved along.

Cables Under Water.

The laying of cables under water is a problem which differs for each individual situation, and such points as cable length and weight, tide, depth of water, navigation and dredging operations must be considered before a suitable method can be decided upon. Fig. 44 shows a cable being laid across the River Thames near Henley. It was placed in a trench dredged in the river bed to a depth of 2 ft. 6 in Guide stakes were driven into the river bed on one side of the trench to ensure correct laying of the cable Finally, the trench was filled with gravel and firmly rammed.

Cables, if properly designed and manufactured, have a remarkably long life under water. Fig. 45 shows four Johnson and Phillips cables, which were laid in Weymouth Harbour in 1903. The photograph was taken recently, when they were lifted and relaid in a new position. The borough engineer's report stated that the cables, armouring and serving were in excellent condition, and there appeared to be no reason why they should not give another 25 years' uninterrupted service.

Jointing.

As the majority of faults on underground cables are found, in reality, to be faults in joint boxes, it would not be proper to conclude this article without some reference to jointing. However, a full description of the various types of joints would be extremely lengthy and the writer proposes, therefore, to give a detail of an L.T. joint and a few general notes only, on the subject. Cable jointing is a highly skilled operation and should not be undertaken by anyone who has not had a long and careful training.

Cleanliness is Important.

It may be said that, assuming that the design and the materials are correct, extreme cleanliness is the most important thing. With this object in view, allow plenty of space for the jointer to work in and line the excavation with tarpaulins to prevent dirt being knocked or blown into the joint. See that all jointing materials are left in their sealed tins until the last moment and carefully clean the lead sleeve and cast iron box of any soil.

Do not carry out any jointing operations in rainy weather and consider that even damp days are unsuitable for E.H.T. joints. See that it is impossible to interchange the box and sleeve compounds and if they are not easily distinguished by sight have them delivered in different shaped tins. Take care that the compounds are heated to and not beyond the correct temperatures.

Fig. 46 shows the cable ends being prepared for a straight through joint on a five-core L.T. cable. The cable has been marked off, the steel tape armouring cut back and the lead sheath removed for the required distance.

Taping Up the Insulation.

The next step is to tape up the insulation so as to protect it during the work and to increase its thickness. This is shown in Fig. 47. Cut off the cores to exact length, bare them and try the jointing ferrules. The cores should be cut so that the ferrules will be staggered. Thoroughly clean and tin the cores and also the ferrules, if they are not supplied already tinned. Slip on the lead sleeve and push it back out of the way. Fig. 48 shows this done and the ferrules in position. Solder the ferrules, using a resin flux, and see that they are completely filled. Remove any surplus solder.

Fig. 49 shows the ferrules insulated with tape to the necessary thickness. Impregnated linen tape 1 in. wide is usually used with ½ in. overlap for L.T. joints and impregnated paper tapes from ¼ in. to 1 in. wide, butted together for E.H.T. joints. On E.H.T. joints spreaders should now be fitted to keep the cores apart and to prevent them touching the lead sleeve. Carefully inspect the joint and the sleeve before moving the latter into position. Tap down the ends of the sleeve and plumb them on to the cable sheathing, as shown in Fig. 50. Inspect the undersides by means of a mirror.

Warm the sleeve and fill slowly with compound. Close down the opening in the top of the sleeve and seal it up. Place the bottom half of the cast iron box in position, warm it and slowly fill it and the box joint with compound. Fix the top half of the box with the filling plate and vent plugs removed and complete the filling. After topping up, screw in the plate and plugs and clamp on the armour grips, as shown in Fig. 51.

HOW TO MAKE A MAGNETO AND COIL TESTING SET

AUTOMOBILE electrical engineers have occasion from time to time to test magneto armatures and ignition coils. The testing set described in this article will enable these tests to be made with accuracy and convenience.

The general arrangement is given in Fig. 4 and from this the position of the various components can be scaled.

The base should be made of hard wood and it is advisable to give it two coats of varnish, after making the 1⅞-inch hole and the 3¾-inch diameter by $\frac{3}{16}$ inch deep recess for the trembler coil unit.

Trembler Coil Unit.

Details of the trembler coil unit are given in Figs. 1 and 3.

The spool is built up of tubing and sheet metal, the flanges being soldered to the tubing as well as the core retaining strip. Special attention is drawn to the slotting of the spool. It is important that this slot is carried right through to the centre of the tube.

Insulating with Cambric.

Wrap the tubing between the flanges with 1½ turns of varnished cambric, using shellac varnish as an adhesive. The inside faces of the flanges should also be insulated with cambric, shellac varnish being used to make the cambric washers adhere to the surface.

The Winding.

A small hole should be drilled in the bottom flange *adjacent* to the tube, through which the beginning of the winding may be passed. The start of the winding is soldered to the outside face of the bottom flange and then the 175 turns close wound on the tube. This will take approximately 5½ layers which will bring the end of the winding about midway between the flanges. Temporarily bind down the end of the winding with cotton tape, taking care to leave a length of 6 inches free for connecting to the battery terminal on the base. Treat the winding with shellac varnish, allowing it to soak well into the winding and dry. Bind the winding for protection with ⅜-inch wide cotton taping and give this a coat of shellac varnish.

Cut off soft-iron wire to lengths of 1¾ inches and pack carefully and tightly in the centre of the tubing, so that the ends are flush. It is a great help in packing the core if each wire is quite straight.

Securing the Coil Fixing Plate.

Next secure the coil fixing plate to the spool by means of three short 4BA screws and fix the unit in the base with three No. 8 wood screws. Drill two No. 10 drill size holes in the base for the two screws for fixing the trembler bridge, using the corresponding holes in the coil fixing plate as a guide.

The trembler bridge is shown in Fig. 1, and is secured in position by two 1½-inch 2BA screws. Two washers should be threaded on one screw for the connection wire to the condenser.

Assembling Contact Spring on Block.

Assemble the contact spring and block and secure to the base with two No. 8 wood screws, taking care the block is clear of the coil fixing plate. The contact for the spring may be made from a magneto contact by turning down the head and screw suitable for riveting over on the spring. This riveting must be carefully done to avoid damaging the face of the contact and also to ensure it is tight and making good contact with the spring. Similarly the soft-iron tip should be securely riveted.

If the adjustable contact screw (Fig. 3) is drilled and tapped at the end to receive a standard magneto contact lever screw,

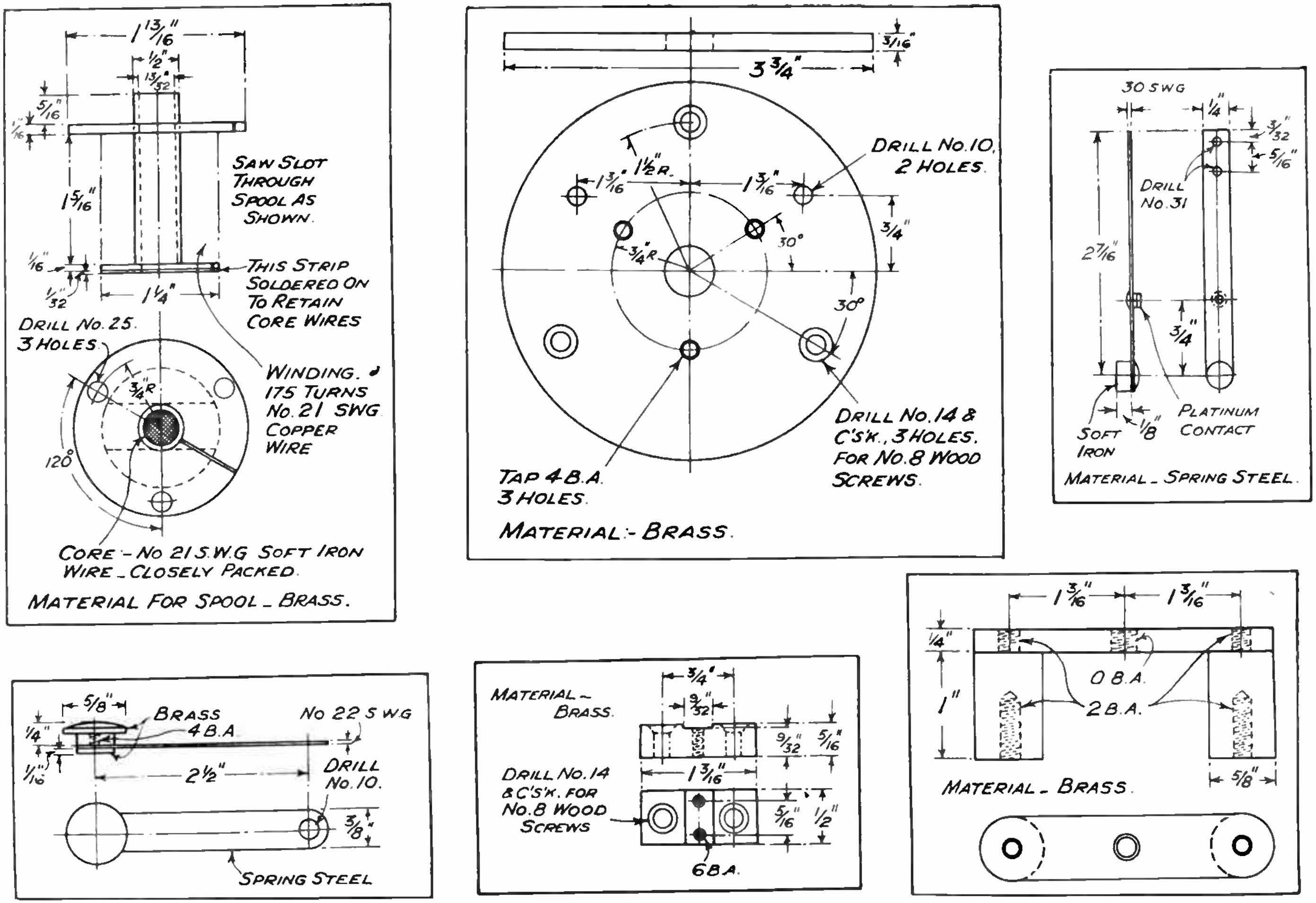


Fig. 1.—DETAILS OF COMPONENTS OF MAGNETO ARMATURE TESTING SET.

From left to right (top), spool assembly; coil fixing plate; trembler contact spring; (bottom), switch key; contact spring block; trembler bridge. (See also Fig. 3.)

replacement will, at any time, be easy. The adjustable contact screw should be fitted in the bridge and the contact fitted.

Spark Gap Stand.

No difficulty should be presented in making the spark gap stand shown in Fig. 3; the most important point being to take care in marking out and drilling the fixing holes and those for the electrodes to ensure good alignment of the latter.

The points of the electrodes are made separate for replacement and preferably should be made from $\frac{5}{32}$ inch nickel rod. For testing armatures, the gap should be set to 7.5 mm. The adjustment of the third point as shown in the sketch is important.

This is the same type of testing gap as is used for checking the slow speed performance of magnetos, the gap then being set to 5.5 mm. By the aid of the drawing, a 4, 6 or even 8 gap stand for multi cylinder magnetos could be constructed. The additional spark gaps would be arranged above the gap shown and spaced about $\frac{3}{4}$-inch apart.

Fix the test gap to the base with two No. 8 wood screws.

Condenser.

A condenser of at least 0.28 m.f. capacity is required to be connected across the trembler contacts to prevent flashing and rapid wear. For this purpose, two standard magneto condensers of about 0.15 m.f. could be used. They should be connected in parallel and secured in any convenient position on the underside ot the base, by wood screws.

Key Switch.

The details for this are shown in Figs. 1 and 3. The press button is drilled and tapped 4BA whilst the tip is provided with a threaded shank for securing both parts to the spring portion. A short 2BA screw and washer is used to secure the spring to the one terminal post. Assemble as shown on the base.

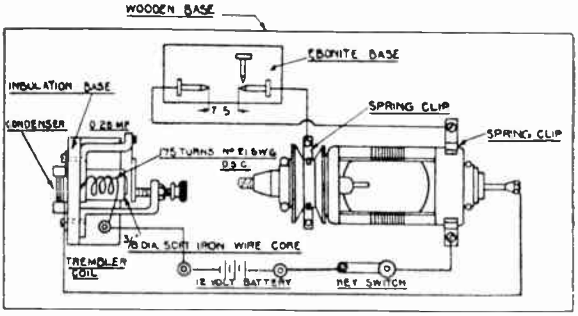


Fig. 2.—CONNECTION DIAGRAM FOR MAGNETO ARMATURE TESTING SET.

Armature Clips.

These are shown in Fig. 3 and can readily be made from sheet phosphor bronze. If spaced on the base as shown, they will be suitable for taking any standard magneto armatures.

Slip Ring Clip and H.T. Cable.

For the connection between the insulated terminal of the spark gap stand and the slip ring, a simple spring clip soldered to a short length of plug cable is all that is necessary.

Battery Terminals.

Any standard 2BA or 6BA terminals may be used for this purpose.

L.T. Connection.

To make connection to the insulated primary terminal of the magneto, a small plug type of connector is necessary, or a contact breaker fixing screw may be used.

Wiring.

Copper wire such as employed for the spool winding may be used for wiring up the set, which should be connected as shown in the general arrangement drawing. Varnished cotton or silk tubing threaded over the wire will prevent fraying of the silk covering. Alternatively lighting flex may be used, and this will certainly be most suitable for the connection lead passing through a hole in the base from the trembler block to the armature L.T. connection.

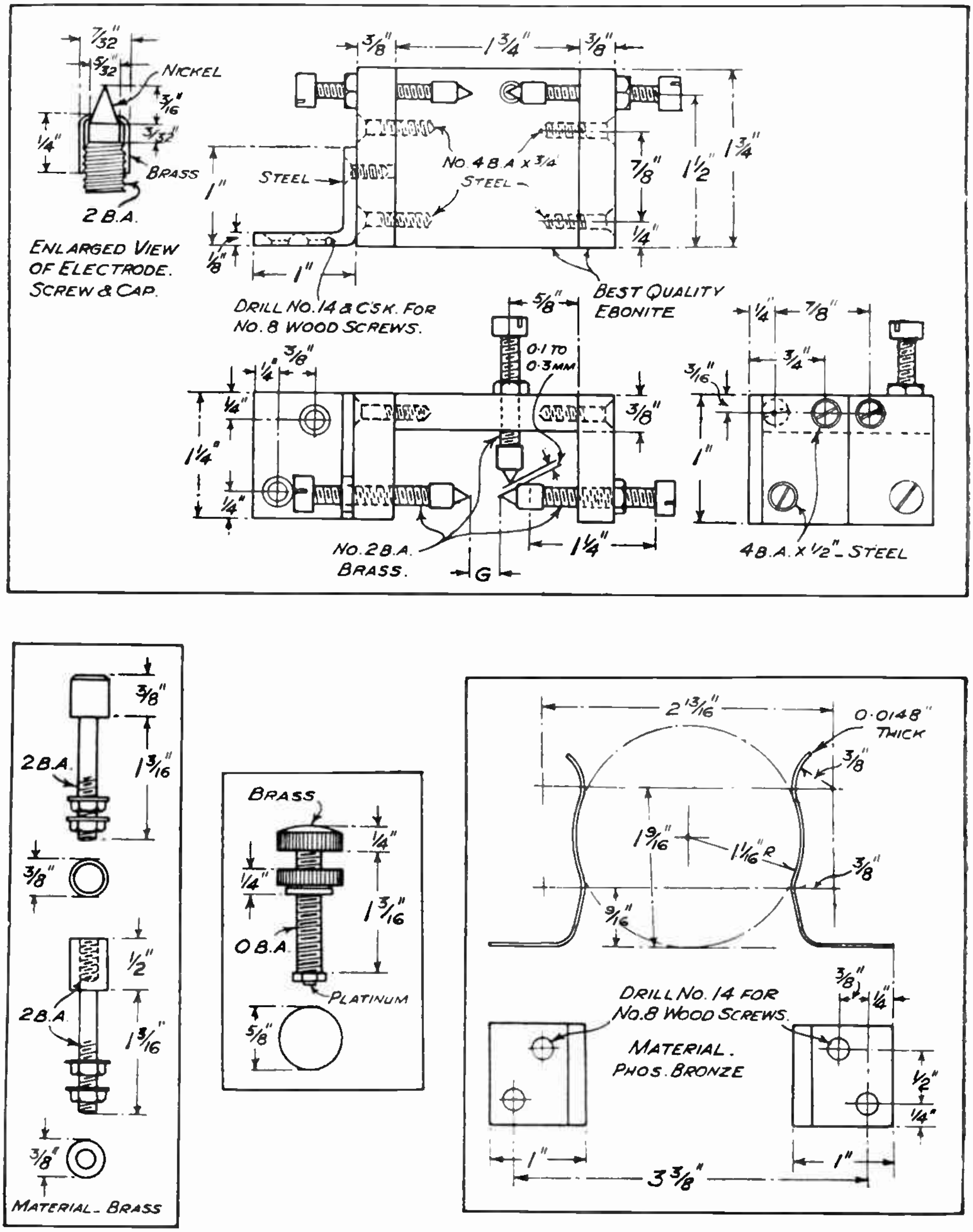


Fig. 3.—MORE DETAILS OF COMPONENTS FOR MAGNETO ARMATURE TESTING SET.

(Top) Three-point spark-gap stand. (Bottom) Switch terminals; adjustable contact screw; armature clips.

Connecting Up the Components.

Connect up the components as follows:

(*a*) Free end of trembler winding to one battery terminal.

(*b*) Contact block to condenser terminal and from this bring lead through the base and attach the plug for connecting to the armature primary connection.

(*c*) The other condenser terminal is connected by a lead to one of the trembler bridge fixing screws.

(*d*) Connect one armature clip to the anchoring post of the key switch.

(*e*) Connect the other key switch terminal post to the unconnected battery terminal.

(*f*) Attach H.T. cable to insulated terminal of the spark gap.

(*g*) The return for the H.T. current from the spark gap is made by connecting the other spark gap terminal to one of the armature clips.

Fig. 2 shows a connection diagram.

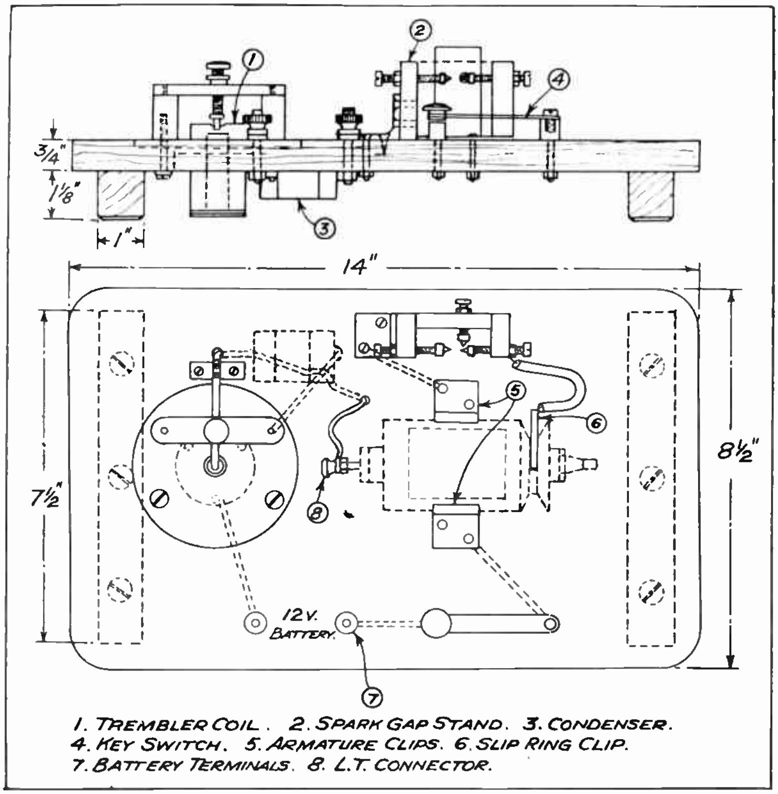


Fig. 4.—General Arrangement of Magneto Armature Testing Set.

Testing.

Place the armature in position between the clips, inserting the L.T. plug connector in the primary terminal and fitting the spring clip attached to the H.T. cable over the slip ring. With a 12-volt battery connected to the battery terminals, the armature should spark frequently and rapidly across the 7.5 mm. gap when the key switch is depressed.

Initially, it will be necessary to adjust and set the trembler contacts. The adjusting screw should be screwed down until the spring blade ceases to vibrate and then gradually unscrewed until the blade vibrates most rapidly and consistently. Fix the adjusting screw in this position by the locknut.

Testing Ignition Coils.

Ignition coils may also be tested on this set. Connect the coil H.T. terminal to the spark gap and the base or fixing bracket of the coil to the earthed side of the spark gap. One L.T. connection of the coil should be connected to the armature clip connected to the switch and the other coil terminal to the lead from the contact block and condenser.

PHOTO ELECTRIC CELLS

By Norman R. Campbell, Sc.D.

Interest in Photo Electric Cells.

THE interest of practical electrical engineers in photo electric cells has begun only in the last few years. Because their interest is so new, engineers are apt to think that the cells are new, that photo electricity is a subject of very recent origin, still in a state of rapid development, and that they have only to wait patiently for the natural growth of knowledge to perfect the rudimentary instruments now at their disposal. It must be made clear at the outset that this is all wrong. Photo-electric cells are much older than thermionic valves; cells not markedly inferior to those of to-day, in the qualities important in most engineering uses, existed in 1895; and when to these were added, in about 1915, the "hard" thermionic valve, all the essential elements of the most modern photo electric apparatus were available. If they were not used, it was because their possibilities were not realised outside a very small circle.

Effect of "Talking Films" on Use of Photo Electric Cells.

The mushroom growth of the "talking film" was largely responsible for the change. Cells were demanded in unprecedented quantities, and their manufacture passed from the hands of amateurs and specialised instrument makers to those of large firms in close touch with the engineering world. Improvements in quality followed, partly, but not entirely, as a result of the change; but many of these improvements were important only for the very specialised purposes of talking-film reproduction and helped little in the application of photo electricity to more general engineering uses. Cells were more widely used simply because the knowledge of their potentialities became more widespread. And the further extension of their use must arise from the same cause. When the ordinary working engineer comes to regard the photo electric cell as one of the normal tools of his craft, like the electro-

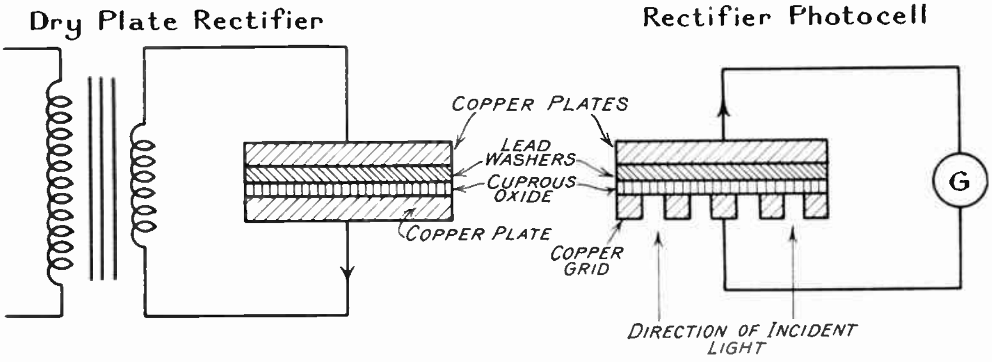


Fig. 1.—Diagram showing Principle of Rectifier Photocell.

When light falls on the boundary between a metal and a semi-conductor of the kind which rectifies a current, an electronic current is caused to flow from the semi-conductor to the metal, i.e., in the direction opposite to that of the rectified current.

magnetic relay or the bimetallic strip, and makes himself familiar with its powers and limitations, then its use will spread rapidly without any improvement in the tool itself or any increase in our knowledge of it. If, on the other hand, he waits to use it until research produces some revolutionary change, he will probably wait for ever.

Why Amplifiers Will Always Be Necessary.

It may be well to enforce this general statement by a particular example. One of the properties of a photo electric cell that immediately strikes the attention of the engineer is its sensitivity, or the amount of current that it will give under the incidence of a given light. The sensitivity at present seems to him very small ; photo electric currents are generally reckoned in microamperes ; he dreams of a time when sensitivities will be so increased that he will have amperes to play with. Such dreams are quite illusory. It is almost certain that no cell will ever give directly, with the amount of light usually available, enough current to work even a telephone relay. The photoelectric control of any kind of mechanism will always require the use of amplifiers. When once amplifiers are introduced, the power available depends in practice far more on the properties of the amplifier than on the properties of the cell.

When Sensitivity is of Small Importance.

In one very important group of applications, in which the cell is used to detect the motion of some object by the interruption of a beam of light, sensitivity is really a matter of very small importance ; enough light is usually available to make the least efficient cell provide all the current that is required to operate the amplifier. In another important group of applications, in which the cell is used to measure light and, thereby, the optical properties of some material, the only quality demanded of the cell is that it should always give the same response to the same light. This quality is possessed in the fullest perfection by some of the oldest types of cell ; no improvement is possible ; and later developments have been retrogression rather than progress.

TYPES OF PHOTO ELECTRIC CELLS.

Now we will proceed to consider in turn each of the types of photo electric cell. Of these there are four. In order of familiarity they are :—

The *conductivity* cell, of which the *selenium* cell is the best known example.

The *emission* cell, often called a photoelectric cell to the exclusion of all others, in which the light causes the emission of electrons from a cathode. The old Elster-Geitel cell and the modern "caesium" cell are the best known examples.

The *voltaic* cell.

The *rectifier* cell.

But the order of familiarity is not the most convenient order for exposition, and we will start with the last.

THE RECTIFIER CELL.

Three classes of photo cell have been known for a generation or more, but the rectifier is a product of the last few years. The Germans, who have done most of the development, but not the first discovery, call it a Sperrschicht or "hinder-layer" cell ; but since it consists of nothing but a metal rectifier (of the type that the Westinghouse Company have brought into such prominence) with one semi-transparent electrode through which light can enter, the term proposed here is more likely to gain acceptance.

Basic Principles.

The basic fact is that when light falls on the boundary between a metal and a semi-conductor of the kind which rectifies a current, an electronic current is caused to flow from the semi-conductor to the metal, i.e., in the direction opposite to that of the rectified current. The combinations most studied so far are copper-cuprous oxide (as in the Westinghouse rectifier) and lead-selenium (as in the rectifier of the Süd-Deutsch A.F.). Judged by the ratio of the current produced to the light incident, these cells are about as sensitive as the best emission cells, but much less sensitive than conductivity cells. Their advantage over both is their great robustness, their cheapness (probably) and the absence of any need for a battery to drive the current. Nothing could be more attractive to the engineer; there is simply a metal plate bearing two terminals between which a current flows when light falls on the plate.

Advantages and Disadvantages.

But unfortunately they have a serious defect for most engineering purposes; the current cannot easily be amplified by thermionic valves, because the cells have a low internal resistance, so that, while they will generate current, they will not generate the volts that the grid requires. Accordingly at present their uses are limited to those in which an output of a few microwatts will suffice. For comparatively rough measurements with the simplest possible apparatus, they are unrivalled; a portable instrument is already advertised whereby illumination can be measured as easily as volts with a voltmeter. But where the light is required to set some mechanism in operation or where a very small amount of light has to produce a large effect, they are not well suited.

Future Developments of Rectifier Cells.

It is difficult to predict how they will develop under the intensive investigation that is being directed on them. Methods of use that will minimise their disadvantages will doubtless be found and the extent of those disadvantages decreased. But it seems unlikely at present that they will replace emission cells in the fields where they are at present employed most widely. Their study is sure to continue, because their theory is very interesting and will probably provide the next great success for wave-mechanics and the modern theory of metallic conduction. Both the rectifying and the photo electric properties of the boundary between metal and semi-metal arise from the ability of electrons to leak *through* a barrier of potential over which they cannot pass without violating the principle of energy.

THE VOLTAIC CELL.

This, on the other hand, is in principle the oldest photo electric effect of all. Becquerch found in 1839 that, if one of the two similar electrodes immersed in an electrolyte were illuminated, an E.M.F. may be produced as in a voltaic cell. But practical cells of this type have only been produced in the last few years; and the Arcturus cell is still, we believe, the only commercial representative of the class. Over all but rectifier cells these cells have the advantage of cheapness, robustness and of requiring no battery; over rectifier cells they have the advantage of greater current-sensitivity. But they share with them the disadvantage of a low internal resistance which makes them unsuited for amplification by thermionic valves; and they suffer, though in a less degree, from the great disadvantage of conductivity cells, namely, that their response is determined by their past history and not merely by the light acting at the moment.

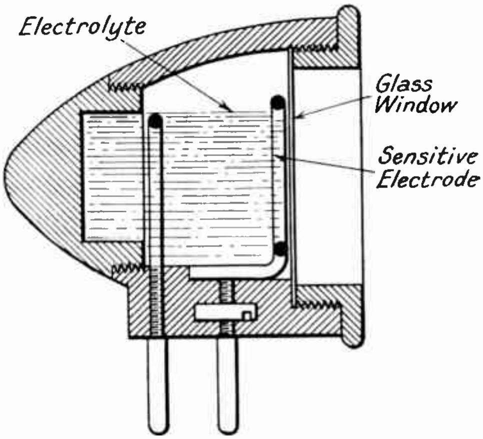


Fig. 2.—Section of Electrolytic Cell.

Problems that have to be Solved.

At present there does not seem to be any field in which photo voltaic cells have an advantage on balance over other types; but their use has probably been hampered by the too exuberant claims that have been made for them, and they certainly demand more notice than they have received up to the present. Little systematic research on this type appears to be in progress. The theory is still wholly obscure and debate still continues whether the underlying action is "photo-chemical" or "photo electric"; the truth is, of course, that the explanation must be sought in the region where these terms cease to be distinguishable. It is not even certain whether all photo voltaic cells are of the same kind, or whether there is a difference between cells (such as the Arcturus) in which the photo electric action seems to occur at the surface of the electrode and those (the subject of many more published investigations) in which it seems to occur in the body of a fluorescent electrolyte. There is here a field for photo electric research that is nearly virgin for the application of modern conceptions and technique.

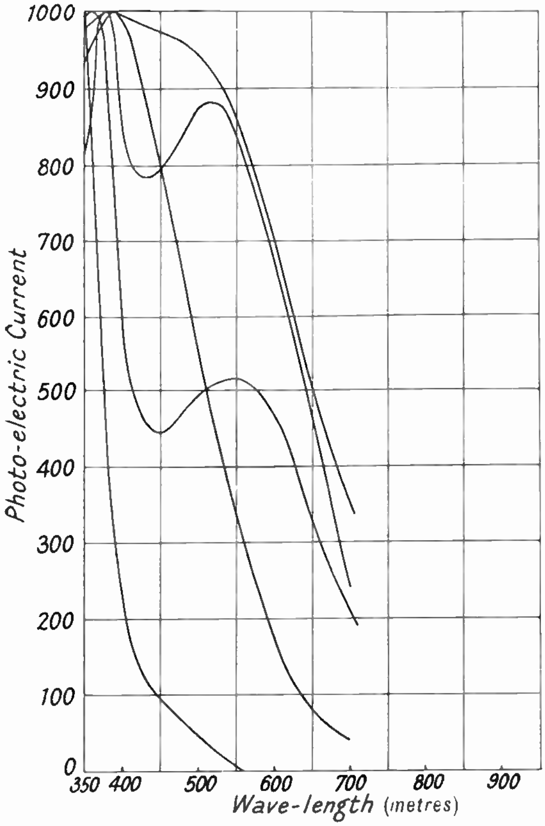


Fig. 3.—Sensitivity Curves Produced by Sensitising Sodium in Different Ways.

Curves reduced to give the same maximum value.

THE CONDUCTIVITY CELL.

The best known example of this class is the familiar selenium cell, which, in spite of predictions and rumours of decease, continues to play an active part in photo electric engineering. Its merits are, of course, its great current-sensitivity; its demerits its irregularity and the very complicated relation between light and response into which past history, as well as temperature and secular changes, enter so largely. The practical problem is to diminish the demerits without affecting the merits; and something has been achieved in this direction during the last few years by modifications of the mechanical construction of cells and the removal of inessential causes of irregularity. But in spite of claims that are made from time to time, it seems improbable that the defects that render the cells useless for measurement and unsatisfactory for such purposes as television and picture telegraphy will ever be greatly reduced.

Substitutes for Selenium.

Renewed attention is being paid to the substitutes for selenium. The production of "thalofide" (thallium-oxy-sulphide) cells has been further investigated; for, if some more trustworthy process for producing these cells could be discovered they would undoubtedly have advantages over selenium in its own particular sphere. They are rather more sensitive and less irregular. Further, the substitution for selenium of the closely related element tellurium or of a mixture of the two has been shown to be advantageous for some purposes.

All this research is still purely empirical; our knowledge of the fundamental processes involved has hardly advanced beyond the stage at which Gudden and Pohl showed how very complicated they must be.

PHOTO EMISSION CELLS.

(*a*) The Sensitivity of the Cathode.

The properties of photo emission cells are determined primarily by the nature of the cathode, which emits electrons under the incidence of the light. Here there has been a revolution, both in theory and practice, during the last few years. We used to speak of "potassium," "caesium" or "cadmium" cells (or cathodes), implying thereby that the photo electric properties of the cathode were determined by the nature of the metal of which it was mainly composed. It was known that the state of the surface of the metal had some influence, and an important process was known whereby the sensitivity of a metal might be increased greatly by a deliberate treatment of its surface; but it was not thought that variations arising in such ways in the properties of a single metal could obscure the much greater differences between different metals.

Difficulties of Defining Photo Electric Properties.

To-day all this is changed. Photo electric sensitivity to visible light still seems to be possessed only by cathodes of which the highly electro-positive metals (and particularly the alkali metals) are a constituent; those metals may therefore still be distinguished as "active" metals; but it is so profoundly modified by the other constituents and by the relation of the various constituents to each other, that there is no important property possessed by all cathodes containing one of these elements that is not shared by some cathodes containing another; there is no longer any sense in speaking of a potassium or a caesium cell; the photo-electric properties can only be defined by some much more detailed specification.

Methods of Manufacture.

But we cannot yet specify a photo-electric cathode accurately by its constitution, we can only state its method of manufacture; the problem of determining what is the constitution produced by a given method of manufacture is one of the gravest of those that still await solution. But methods of manufacture are becoming classified and standardised. They fall into two groups.

Sensitisation Methods.

First there are methods of sensitisation which may be regarded as developments of the old Elster-Geitel process of subjecting a surface of an alkali metal to an electric discharge in hydrogen. In these the active metals are caused to undergo a controlled reaction with some gas or vapour, so that a film consisting partly or wholly of a chemical compound is formed on their surface; on this film a layer of the unsensitised metal may be deposited; this may be subjected to another reaction. And so on—for many variants and elaborations of the procedure are possible. Olpin, who has been the chief worker in this field—has studied in great detail the sensitisation in this manner of the alkali metals—and especially sodium—by reaction with compounds containing sulphur and oxygen, ranging from SO_2 to complicated dyes containing sulphite radicals.

Early Experiments.

At first he seemed to obtain evidence that a photo electric cathode might be sensitised by a dye in much the same way as a photographic plate, acquiring the power to absorb and utilise light within the range of an absorption band identical with, or closely related to, that of the dye. But this idea has had to be abandoned.

Present-day Discoveries.

Most of the sensitised metals show spectral selectivity; that is to say the sensitivity, measured by the current per unit of energy in the incident light, is a maximum for some wavelength and does not increase steadily as the wavelength decreases. But the position and height of this maximum cannot be related simply to the properties of the sensitising compound. Indeed, it appears possible now that the action of all the great variety of sensitising compounds investigated may be fundamentally the same and that differences arise rather from the speed of the reaction than from its nature; it is even possible that the true sensitiser in all cases is the same, either a radical or an impurity common to all the reagents used.

Finding the Correct Combination.

Further, the processes are not easily controlled, and it is not always possible to reproduce the same sensitivity by repeating the same process. However, there is no doubt that a very great variety of cathodes sensitive to different parts of the visible spectrum can be produced by these processes, including some having a sensitivity to white light considerably greater than any known until a few years ago. The field does not seem to be exhausted, and the trial of new combinations may produce yet more valuable results.

Thin-film Method.

The other method of manufacture may be regarded as arising out of Ives' work on thin-films. Ives showed that a film of an active metal, probably only one atom thick, on the surface of an inactive metal, conferred on it a photo electric sensitivity which was not the same as that of the active metal in bulk and depended on the thickness of the film. Such films, deposited on clean inactive metals, do not appear to be practically useful; but when they are deposited on various chemical compounds (sometimes mixed with metals) a very valuable series of cathodes is obtained, most of which possess spectrally selective sensitivity in the visible region.

How Cathodes Can Be Prepared.

Cathodes of this kind can be prepared by simply exposing a surface of the underlying compound (such as calcium fluoride) to the vapour of the active metal (for all the alkali metals have appreciable vapour pressures at room temperature) and allowing a film to condense on the surface spontaneously; or a thick layer may be deposited and the excess over the thin layer which gives the best result distilled off by heat. In a modification of this last process the underlying compound is formed and the film deposited on it in a single operation. Thus a cathode of great practical inportance is made by heating an oxidised silver plate in the presence of caesium vapour, whereby the silver is reduced and caesium oxide produced, and then distilling off the excess caesium, leaving only the thin film adhering to the compound surface thus formed.

Difficulties of Reproducing Cathodes.

The variety of cathodes that can be produced by this process is probably no less than that which can be produced by the first. But again there is difficulty in reproducing the same result by repeating the process. Experiments on new combinations will doubtless proceed for some time to come, and it is possible that improvements in photo emission cells comparable with the replacement of the Elster and Geitel cell by its modern substitutes may still be in store for us.

The Uses of Cathodes.

But since it may appear that something new and valuable *must* emerge from the immense field of possibilities that now presents itself, it may be well to observe that our requirements are very limited. So far as uses at present foreseeable are concerned they are: (1) a cathode with the greatest possible sensitivity to white light, including in that term the radiation from all ordinary illuminants; (2) a cathode whose sensitivity extends as far as possible into the infra-red; (3) a cathode whose variation of sensitivity with wave-length agrees as nearly as possible with the " visibility " curve of the normal eye; (4) a cathode with a very uniform sensitivity over a very wide range of wavelengths; (5) a cathode specially sensitive to the ultra-violet radiation of wavelength about 3000 A, which has special biological significance.

Possible Developments.

(1) and (2) will probably be the same, since most of the energy of artificial " white " sources lies so far in the red that it is not fully utilised at present. The search for the best cell in this respect has probably been prosecuted more energetically than any other, and the chance of improvement on that which now holds the field (the caesium-silver-oxygen cell

mentioned above) is therefore least. But rumours of an advance are already in the air, though so far they are unsupported by evidence. An advance in the direction of (3) is more probable; for no cell produced regularly at present approaches the ideal; while some of Olpin's experimental cathodes appear to come very near it. This requirement is important, of course, in all photometric work in which visual judgment is the ultimate criterion.

(4) is required for spectrophotometric work. It is highly unlikely that any close approximation to the ideal will be attained; for in the visible spectrum strongly selective sensitivity, with one or more marked maxima, is characteristic of all cathodes; the best that can be hoped for is several equal maxima. But real improvement in this direction cannot be expected until consistency in producing the same properties by the same process is attained; for uniformity among different cells is almost as important as uniformity in the same cell.

(5) will probably not be provided by either of the new processes that have been described; for the characteristic sensitivity of cathodes produced by them is in the visible spectrum. It is possible that the extension of the same process to less electro-positive metals might produce a selective sensitivity in the ultra-violet; but so far the considerable advances that have been made in this direction have come from simply trying metals that hitherto have not been investigated at all, e.g., uranium and thorium. A comparative study of all the metals in their "normal" state ought to be undertaken.

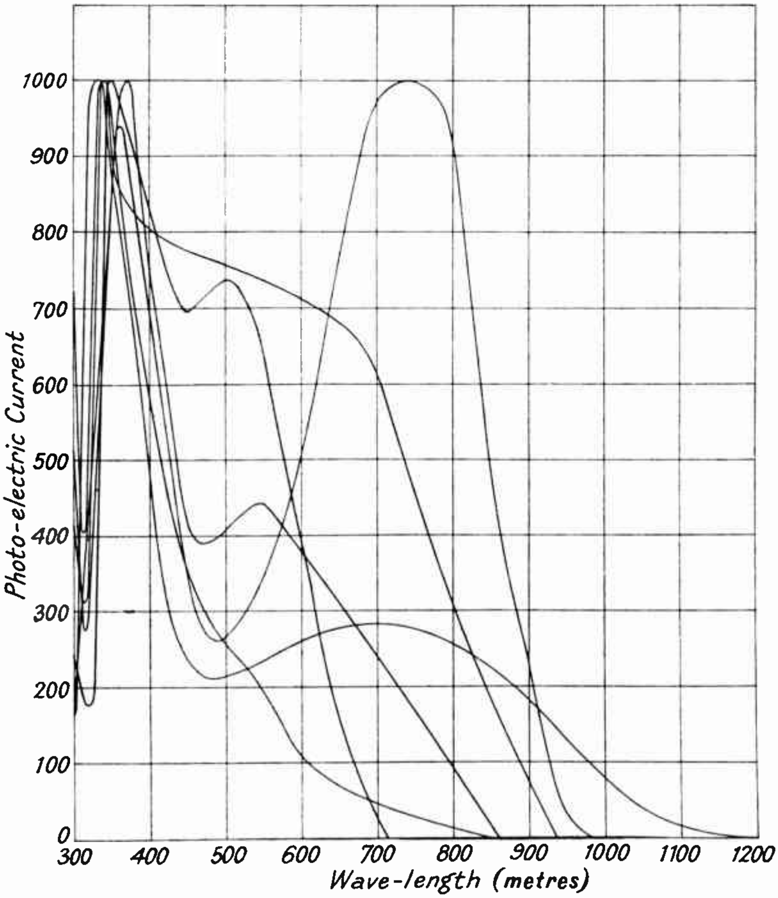


Fig. 4.—SENSITIVITY CURVES OF VARIOUS THIN FILM CATHODES. Curves reduced to give the same maximum value.

Selective Sensitivity Not Yet Understood.

For even if all practical problems were solved, photo electric emission would still be worthy of study. The theory of it, though of the greatest importance in pure physics, is still very incompletely understood. The action of the light is doubtless to give to the metallic electrons an energy sufficient to enable them to emerge against the opposing field at the surface; but we still do not understand why there should be *selective* sensitivity and why a particular wavelength should be more effective than wavelengths either greater or smaller. Classical theories had to seek the cause in selective absorption of the light and to hold that the electrons took energy at one wavelength more readily than at another. Wave-mechanics showed that the cause might be selective emission; that electrons with a particular energy might emerge more easily; and that this was most likely to happen when the surface was built up of layers of different materials, as are probably all the selectively sensitive surfaces prepared by either of the processes described.

But it seems possible that such a structure might also give rise to selective absorption of the light; so that the selective emission theory does not seem necessary. A decision between the two theories might be obtained if it could be shown that selective sensitivity is always associated with selective optical absorption; for though the energy carried by the emerging electrons is never more than a small fraction of that lost by the light when it falls on the surface, a maximum in one would be expected to accompany a maximum in the other if the theory of selective absorption is true and that of selective emission false.

(*b*) Gas-filling.

In gas-filled cells other problems besides that of the cathode enter. The great increase in the sensitivity of vacuum cells that has been obtained by the substitution of the newer for the older cathodes has not been fully realised in gas-filled cells, because less magnification can be obtained by means of ionisation of the gas.

Degree of Magnification with Gas-filled Cells.

In an old "potassium" cell the primary current could be magnified 50 times and yet be stable; in a new "caesium-silver" cell it can only be magnified 20 times for the same stability.

"Time-lag" of Gas-filled Cells.

When this re-examination is made it will probably throw light on an obscure phenomenon of increasing practical importance, namely the slight "time-lag" of gas-filled cells, which prevents them following accurately very rapid fluctuations of light. The effects of this time-lag are appreciable in the reproduction of talking-films and in picture telegraphy; they become very serious in television, which involves frequencies of fluctuation up to 100,000 p.p.s. At present gas-filled cells lose almost all their superior sensitivity over vacuum cells at such frequencies. Of course, it is not certain that a better understanding of time-lag will enable its effects to be avoided; but research in this direction is urgently required on practical as well as on theoretical grounds.

AMPLIFIERS.

Amplifiers are so intimately involved in most engineering applications of photo electric cells that a word must be added about two recent developments.

The Thyratron Relay.

The advent of the "thyratron" (or gas-filled thermionic relay) enables the current that can be controlled efficiently by a photo electric cell to be increased from a few milliamperes to many amperes. Of course, the same increase can be obtained by placing a mechanical relay or contactor in series with an amplifying valve of the older type, but in many cases the thyratron has very definite advantages, especially in being adapted for A.C. supplies. The combination of cell and thyratron will probably play a large part in the engineering of the future.

Amplifier Valve for Photo Electric Work.

Another new kind of amplifier valve specially adapted for photo electric work is that in which grid current is almost totally suppressed by using very low anode potentials and taking especial care about insulation. With such valves there is practically no limit in principle to the smallness of the photo electric current that can be made to work a relay or a robust measuring instrument, if only sufficient time is allowed; the field of measurements commercially practicable is considerably extended.

SIMPLIFIED CALCULATIONS RELATING TO D.C. AND A.C. MOTORS AND DYNAMOS

By A. T. Dover, M.I.E.E.

D.C. MOTORS.

Quantities Usually Involved with D.C. Motors.

THE practical man may occasionally require to calculate the following: Resistances of windings, temperature rise, efficiency, current input at full load, no load losses.

The tester must, in addition, be able to: Correct test speed readings for variation of supply voltage, machine temperature, excitation, and load; calculate speed, torque and efficiency curves; calculate saturation curves from indirect tests; separate the losses in a machine into its components.

Resistances of Windings.

To calculate the resistance of one of the field coils of a motor we must know: (1) the number of turns; (2) the mean length of turn (or alternatively, the inside and outside diameters of the coil); (3) the size of the wire; (4) the specific resistance. The total length of wire in the coil is obtained by multiplying the number of turns by the mean length of turn. The resistance is then calculated from the formula:—

$$\text{Resistance} = \frac{\text{length} \times \text{specific resistance}}{\text{cross section}}$$

The value to be used for the specific resistance must be that corresponding to the temperature of the conductor, and may be obtained from Table I.

Alternatively, the resistance may be obtained from Table V, p. 1049, when the length of wire and the cross section are known, but in this case, the result will be correct only at a conductor temperature of 60° C.

Temperature Rise.

The average temperature rise of the field and armature windings can be calculated when the hot and cold resistances of the windings are known. The cold and hot resistances are measured in the usual way by means of an ammeter and a voltmeter, but the air temperature at which the cold resistance is measured must be observed. The *percentage* change of resistance, from cold to hot, is then calculated, and the temperature rise is obtained by dividing this quantity by the coefficient—given in Table II—corresponding to the temperature at which the cold resistance was measured. Expressed as a formula, we have:—

$$\text{temperature rise} = \frac{(\text{hot resis.} - \text{cold resis.})}{\text{cold resis.}} \times 100 \div \text{coefficient in Table II} \quad \ldots\ldots\ldots (1)$$

For example, if the cold resistance is 200 ohms at 60° F. and the hot resistance is 230 ohms, the percentage increase in resistance is $\left(\frac{230-200}{200}\right) \times 100 = 15$ per cent.

From Table II the coefficient on the Fahrenheit scale for 60° F. is 0.222.

TABLE I.—Values of Specific Resistance of Annealed Copper at Various Temperatures.

Temperature °F.	32	60	68	132	140	158
Temperature °C.	0	15.5	20	55.5	60	70
Specific resistance (microhms per in. cube)	0.614	0.667	0.68	0.76	0.77	0.798

TABLE II.—RESISTANCE COEFFICIENT FOR TEMPERATURE RISE.

Temperature at which cold resistance was measured (°F.)	32	40	50	60	70	80
Percentage Coefficient for temperature rise on Fahrenheit Scale	0.237	0.232	0.227	0.222	0.217	0.213
Temperature at which cold resistance was measured (°C.)	0	10	15	20	25	30
Percentage Coefficient for temperature rise on Centigrade Scale	0.426	0.409	0.4	0.393	0.385	0.378

NOTE.—The values of the coefficients are based upon the observed fact that for each °C. difference of temperature from 20° C. the specific resistance of annealed copper changes by $\frac{1}{254.5}$ of its value at 20° C. Similarly for each °F. difference of temperature from 60° F. the specific resistance changes by $\frac{1}{450}$ of its value at 60° F.

Hence the temperature rise $= \frac{15}{0.222} = 67.6^\circ$ F.

Numerical Examples on Resistance and Temperature Rise.

(1) *One of the shunt field coils of a motor is wound with 1800 turns of No. 23 S.W.G. wire. The mean length of turn is 18 in. What is the resistance of the coil at 60° F?*

Solution.—The total length of wire on the coil is $1800 \times 18 = 32400$ in. The cross section of No. 23 S.W.G. is 0.000452 square in., and the specific resistance of copper at 60° F. is 0.000000667 ohm.

Hence the resistance $=$

$$\frac{32400 \times 0.000000667}{0.000452} = 47.9 \text{ ohms.}$$

(2) *The armature of a two-pole motor has 22 coils, and each coil consists of 9 turns of two 0.044-in. wires wound in parallel. The mean length of turn is 30 in. What is the working resistance of the armature (i.e., the resistance between the brushes) at 60° C?*

Solution.—Two 0.044-in. wires in parallel are equivalent to a single conductor having a cross section $2 \times 0.785 \times 0.044^2 = 0.00304$ sq. in.

With a two-pole armature winding there are two parallel circuits between the brushes, each circuit consisting of one half of the *total* turns on the armature. Hence in the present case the equivalent length of wire in one half of the armature winding is $\frac{1}{2} \times 22 \times 9 \times 30 = 2970$ in.

Hence the resistance of one half of the winding is

$$\frac{2970 \times 0.000000667}{0.00304} = 0.65 \text{ ohm,}$$

and as the two halves of the winding work in parallel the working resistance of the armature is $\frac{1}{2} \times 0.65 = 0.375$ ohm.

(3) *The cold resistance test on the field winding of a motor gave a resistance of 68 ohms, the air temperature at the time of the test being 15° C. After running on load for several hours the hot resistance of the winding was measured and found to be 80 ohms, the air temperature being 18° C. Calculate the temperature rise by resistance and the hot temperature of the field winding.*

Solution.—Applying formula (1) to obtain the temperature rise with respect to the temperature at which the *cold* resistance was measured, we have temperature rise (from 15° C.) $=$

$$\left(\frac{80-68}{68}\right) \times 100 \div 0.4 = 44^\circ \text{ C.}$$

Hence, temperature rise from 18° C. $= 44-(18-15) = 41^\circ$ C.

Whence, hot temperature of the field winding $= 41+18 = 59^\circ$ C.

NOTE.—The hot temperature is a *mean* temperature. Certain parts of the winding (e.g., the outer layers) will have a lower temperature than the calculated value, and other parts at the centre of the coil will have a higher temperature.

Efficiency and Current Input at Full Load.

The efficiency of a machine is calculated by dividing the output by the input, both of these quantities being expressed in the same units. When the output and the losses corresponding to this output

TABLE III.—AVERAGE FULL-LOAD EFFICIENCIES OF STANDARD D.C. MOTORS (HOT, 60° C.).

Rated h.p.	$\frac{1}{8}$	$\frac{3}{4}$	1	2	5	10	20	50
Per cent. Efficiency..	60	75	77	82	83	85	87	90

are known, the efficiency can be calculated in the manner explained on page 1174.

In practice we often require to calculate the full-load current of a motor, in which case we must know the efficiency. If this is not known for the particular machine the approximate value may be obtained from Table III, which gives the average efficiencies of motors.

Hence, full-load current=

$$\frac{746 \times \text{h.p.}}{\text{volts} \times \text{efficiency}} \quad \cdots\cdots\cdots \quad (2)$$

No-Load Losses.

In a shunt-wound motor these losses comprise: (1) the shunt-field or excitation loss; (2) the armature core or iron loss; (3) the friction and windage losses. These losses remain practically constant at all loads. They may easily be determined by measuring the current input to the motor when running light at normal voltage; the product of these quantities being equal to the no-load losses.

Efficiency and Current Input at Fractional Loads.

When the no-load losses of a shunt-wound motor and the resistance of the armature are known, the efficiency at inputs smaller than the full-load input can easily be calculated. Thus, the total losses consist of the no-load losses (which remain constant at all loads) and the armature I^2R losses (which can be calculated from the armature current and resistance).

For example, if the no-load losses of a 5 h.p., 110-volt, shunt-wound motor are 415 watts (of which 180 watts is the excitation loss), and the armature resistance is 0.28 ohm, the total losses when the current input to the armature is 20 amp. (which is one-half of the full-load armature current) will be

$$415 + 0.28 \times 20^2 = 527 \text{ watts.}$$

The input to the motor $= 20 \times 110 + 180 = 2380$ watts. Hence, the output $= 2380 - 527 = 1853$ watts. Therefore, the efficiency $= 1853/2380 = 0.778$.

The calculation of the current input corresponding to a definite output is not quite so simple as the above calculation, as the extraction of a square root is involved. For example, if the current input to the above 5 h.p. motor were required when the output was $2\frac{1}{2}$ h.p. we should have to proceed as follows:—

The power output $= 2.5 \times 746 = 1865$ watts, and the power input $= 1865 +$ losses. Since the no-load losses are 415 watts, the total losses when the motor is developing $2\frac{1}{2}$ h.p. are: $(415 + \text{armature } I^2R \text{ loss}) = 415 + I^2 \times 0.28$, where I is the current input to the armature. Hence the power input $= 1865 + 415 + I^2 \times 0.28$.

But the power input is also equal to:—(power input to armature + excitation loss) $= 110\,I + 180$. Hence $1865 + 415 + I^2 \times 0.28 = 110\,I + 180$ which, when solved for I, gives

$$I = 20.1 \text{ amp.}$$

Therefore, the current input to the motor for an output of $2\frac{1}{2}$ h.p. is $20.1 + 180/110 = 21.74$ amp.

Numerical Examples on Input Current.

(1) *What is the approximate full-load current for a 3 h.p. 460-volt motor?*

Solution.—From Table III the full-load efficiency is 82 per cent.

Whence, full-load current=

$$\frac{746 \times 3}{460 \times 0.82} = 5.94 \text{ amp.}$$

(2) *The speed-torque characteristics of a* 15 *h.p. series-wound crane motor at* 220 *volts are as follows:*—

Amperes	90	72	60	45
Torque (lb.-ft.) ..	252	187	148	102
Speed (r.p.m.) ..	435	485	522	580

Calculate the current input at full load.

Solution.—This problem is solved with the aid of squared paper. The output (h.p.) is calculated from the values of torque and speed, using the formula:—

$$\text{h.p.} = \frac{6.28 \times \text{torque (lb.-ft.)} \times \text{speed (r.p.m.)}}{33{,}000}$$

The results together with the current input are plotted on squared paper. The current input for an output of 15 h.p. is then obtained directly from the curve. Thus, the calculated results are :—

Amperes	90	72	60	45
Horse-power ..	20.9	17.3	14.7	11.26

Whence, from the curve, the full-load current is 61.3 amp.

Correction of Test-Speed Readings for Variation of Supply Voltage.

In testing motors it frequently happens that readings of the speed and other quantities have to be taken when the supply voltage differs slightly from the normal value. With series-wound motors the speed corresponding to normal voltage may easily be calculated as for a given current, the flux and torque are independent of the supply voltage. The speed is then directly proportional to the counter-e.m.f. in the armature. Thus if the speed n_1 is observed at a terminal voltage V_1 when the current is I, the current speed n, at normal voltage V, for this current is given by the formula :—

$$n = n_1 \frac{V - IR}{V_1 - IR} \quad \ldots\ldots\ldots\ldots (3)$$

where R is the resistance of the motor.

With a shunt-wound or a compound-wound motor an accurate correction of the speed can only be made when the magnetisation curve of the motor is available. If the difference between the test voltage and normal voltage is small, the flux corresponding to a given current may be assumed to be constant, and the correction is applied in the same manner as for a series wound motor.

Numerical Examples on Correction of Speed.

(1) *In a test on a series-wound motor the speed was 800 r.p.m. when the terminal voltage was 400 volts and the current input 20 amperes. What is the speed for the same current input when the terminal voltage is 460 volts? Resistance of motor* 1.5 *ohms.*

Solution.—The voltage drop in the motor at a current of 20 amperes is 20 × 1.5 = 30 volts. Hence when the terminal voltage is 460 volts, the counter-e.m.f. is 460 − 30 = 430 volts, and when the terminal voltage is 400 volts the counter-e.m.f. is 400 − 30 = 370. Whence, substituting in formula (3) the speed at 460 volts is :—

$$n = 800 \times \frac{430}{370} = 920 \text{ r.p.m.}$$

(2) *In a test on a* 105-*volt shunt-wound motor the supply voltage was* 100 *volts when the current input was* 20 *amperes, the speed being* 1100 *r.p.m. What is the approximate speed at normal voltage? Resistance of armature* 0.4 *ohm.*

Solution.—Substituting in formula (3) we obtain the speed, at normal voltage, as

$$n = 1100 \times \frac{105 - 20 \times 0.4}{100 - 20 \times 0.4}$$

$$= 1160 \text{ r.p.m.}$$

Calculation of Flux.

The e.m.f. (E) generated in the armature of a direct-current machine (motor or generator) is given by the formula :—

$$E = \frac{p}{a} \times \frac{F\ z\ n}{100{,}000{,}000} \quad \ldots\ldots\ldots\ldots (4)$$

where p = number of poles, a = number of circuits in armature winding (usually two in small motors, but equal to the number of poles, p, in lap-wound armatures), F = flux per pole, z = number of armature conductors, n = speed of rotation in revs. per *second.*

Whence, the flux is given by :—

$$F = \frac{100{,}000{,}000}{z\ \ n\ \ p/a} E \ldots\ldots\ldots (5)$$

The generated voltage, E, may be measured when the machine is running as an unloaded generator at a known speed n, or alternatively, the speed n may be determined when the machine is running as a motor, and the counter-e.m.f. calculated.

Calculation of Speed.

Formula (4) can be rearranged to give the speed of a motor when the counter-e.m.f. (E), the flux (F) and the other quantities are known. Thus :—

$$n = \frac{100{,}000{,}000\ E}{F\ \ z\ \ p/a} = \frac{100{,}000{,}000\ (V - IR)}{F\ \ z\ \ p/a} \ldots (6)$$

This formula gives the speed in revs. per second.

Numerical Example on Calculation of Flux.

A 4-*pole shunt-wound motor runs at a speed of* 1500 *r.p.m. at no load when the terminal voltage is* 230 *volts. The armature has a wave (two-circuit) winding with* 900 *conductors. Calculate the flux.*

Solution.—In this case the counter-e.m.f. in the armature is practically equal to the terminal voltage. Also $p/a=2$; $z=900$; $n=1500/60=25$. Whence, substituting in formula (5):—

$$F=\frac{100{,}000{,}000\times 230}{900\times 25\times 2}=510{,}000 \text{ lines.}$$

Calculation of Torque.

The torque exerted by the armature conductors can be calculated when the flux, armature current, number of armature conductors, number of armature circuits and number of poles are known. The formula is:—

$$\text{Torque (lb.-ft.)}=\frac{p}{a}\times\frac{F\ z\ I}{852{,}000{,}000}\quad\ldots\ldots(7)$$

In this formula I is the current input to the armature. The other symbols denote the same quantities as in formula (4).

The torque calculated from formula (7) is the *gross* torque, which is greater than the torque available at the pulley by an amount equal to the torque required to supply the friction, windage and armature core losses.

Numerical Example on Calculation of Torque.

Calculate the torque developed by a 4-pole motor when the current input to the armature is 40 amp. The flux is 500,000 lines, and the wave (two-circuit) armature winding has 450 conductors.

Solution.—In this case $p/a=2$, $z=450$, $I=40$. Hence, substituting in formula (7)

$$\text{Torque}=2\times\frac{500{,}000\times 450\times 40}{852{,}000{,}000}=21.1 \text{ lb.-ft.}$$

Speed-Torque Characteristics.

The speed and torque may each be calculated by means of formulæ (6), (7), when the relationship between the flux and the armature current is known. But in practice we may be given the speed-torque curve of a motor and may require to calculate another speed-torque curve for different operating conditions, such as a different voltage or a different excitation.

With a series-wound motor the speed-torque characteristics for a different voltage is easily obtained from the given characteristic, as, for any given current, the torque is independent of the voltage and the speed is calculated from formula (6). The calculation of the speed-torque characteristic of a series-wound motor corresponding to different conditions of excitation (e.g., a reduction in the number of turns in the field winding (tapped field) or the shunting of the field winding by a resistance) is also a straightforward process, as the magnetisation characteristic of the motor can be calculated from the speed curve. The method of procedure is shown in the numerical example below.

With a shunt-wound motor the magnetisation characteristic, or alternatively the relationship between the speed and excitation at constant load and voltage, must be available before the new speed-torque curve can be calculated.

Numerical Examples on Calculation of Speed-Torque Characteristics.

The characteristics of a series-wound crane motor at 220 volts are as follow:—

Current (amp.)	90	72	60	45	30
Speed (r.p.m.) .. .	435	485	522	580	700
Torque (lb.-ft.) .. .	252	187	148	102	58

Deduce the characteristics when the terminal voltage is 200 volts. Resistance of motor, 0.46 ohm.

Solution.—The torque corresponding to a given current will be the same at both voltages. The speed at 200 volts is calculated by means of formula (3). The calculations are best carried through in tabular form. Thus:—

Current (amp.) ..	90	72	60	45	30
Voltage drop	41.4	33	27.6	20.7	13.8
Counter-e.m.f. at 220 v.	178.6	187	192.4	199.3	206.2
Counter-e.m.f. at 200 v.	158.6	167	172.4	179.3	186.2
Speed at 200 v. (r.p.m.)	387	433	467	526	632
Torque at 200 v. (lb.-ft.)	252	187	148	102	58

(2) *If in the motor of the preceding example one-third of the turns of the field winding are cut out of circuit, what will be the new speed-torque characteristic at 220 volts? Resistance of motor with tapped field winding = 0.4 ohm.*

Solution.—The relationship between the flux and excitation must first be calculated. The actual value of the flux cannot be obtained because data of the armature winding are not available, but the proportional flux is all that is required for the present calculation. This quantity ($k\,F$) is easily calculated by means of formula (5).

For example, from the given characteristics the speed at 60 amp., 220 volts is 522 r.p.m. The counter-e.m.f. is 220—

27.6=192.4 volts. Therefore, substituting in formula (5) :—

$$kF=\frac{\text{counter-e.m.f.}}{\text{speed}}=\frac{192.4}{522}=0.368$$

Carrying the steps through in tabular form we have :—

Current (amp.)	90	72	60	45	30
Speed (r.p.m.)	435	485	522	580	700
Voltage drop	41.4	33	27.6	20.7	13.8
Counter-e.m.f. at 220 v.	178.6	187	192.4	199.3	206.2
kF	0.41	0.385	0.368	0.343	0.294

The values of kF and current are plotted on squared paper, and a curve is drawn through the points. This curve represents the magnetisation characteristic of the motor and is used in the following manner to obtain the proportional fluxes when the motor is operating with tapped field.

With tapped-field operation (i.e., when one-third of the field winding is cut out) the excitation corresponding to a given armature current is two-thirds of that for full-field operation (i.e., when the whole of the field winding is in circuit). Hence, the proportional fluxes are obtained directly from the magnetisation characteristic at currents two-thirds of the corresponding armature currents. For example when the armature current is 60 amp. the excitation is equivalent to $\frac{2}{3}\times 60=40$ amp., for which the proportional flux is 0.329.

The speed corresponding to a given armature current and supply voltage is *inversely proportional* to the flux and *directly proportional* to the counter-e.m.f. Hence, "tapped-field" speed = "full-field" speed $\times\dfrac{\text{full-field flux}}{\text{tapped-field flux}}$

$$\times\frac{\text{tapped-field counter-e.m.f.}}{\text{full-field counter-e.m.f.}}$$

The torque corresponding to a given armature current is directly proportional to the flux. Hence "tapped-field" torque

$$=\text{“full-field” torque}\times\frac{\text{tapped-field flux}}{\text{full-field flux}}$$

This relationship is strictly correct only when *gross* torque (i.e., the torque exerted by the armature conductors) is considered.

The calculations are completed in tabular form, thus :—

Armature amp. ..	90	72	60	45	30
Proportional flux, full field	0.41	0.385	0.368	0.343	0.294
Equivalent excitation, tapped field (amp.) ..	60	48	40	30	20
Proportional flux, tapped field ..	0.368	0.348	0.33	0.294	0.23
Counter-e.m.f., full field	178.6	187	192.4	199.3	206.2
Counter-e.m.f., tapped field	184	191.2	196	202	208
Speed, full field (r.p.m.)	435	485	522	580	700
Speed, tapped field (r.p.m.)	500	562	593	684	900
Torque, full field (lb.-ft.)	252	187	148	102	52
Torque, tapped field (lb.-ft.)	226	169	132.7	87.4	40.7

Correction of Speed for Variation of Machine Temperature.

In a test report of the performance of a motor it is customary to give the speeds for a standard machine temperature, e.g., 60° C. or 140° F. If the test speeds have been obtained at another machine temperature they are corrected to the standard temperature. The correction is easy with a series motor, but is more difficult with a shunt motor as in this case the magnetisation curve must be available.

Thus with a series motor the resistances of the field and armature windings of the motor at the time of the test are measured together with the temperatures. These are corrected to the standard machine temperature, and the counter-e.m.f.'s are calculated. As the speed for a given current is proportional to the counter-e.m.f., the corrected speed is easily obtained. Thus :—

$$\text{speed at s't'd. temp.}=\text{test speed}\times\frac{\text{counter-e.m.f. at s't'd. temp.}}{\text{counter-e.m.f. at test temp.}}\;\ldots\ldots(8)$$

With a shunt motor the change of resistance of the field winding causes a change of flux. Hence the magnetisation characteristic of the motor must be available if the change of flux corresponding to the change of excitation is to be obtained. The corrected speed for a given armature current and normal voltage is then obtained from the formula :—

$$\text{speed at s't'd. temp.}=\text{test speed}$$
$$\times\frac{\text{counter-e.m.f. at s't'd. temp.}}{\text{counter-e.m.f. at test temp.}}$$
$$\times\frac{\text{flux at test temp.}}{\text{flux at s't'd. temp.}}$$

Numerical Examples on Correction of Speed for Temperature.

(1) *The following readings were obtained*

on a series-wound motor at its normal voltage (220 *volts*) :—

Amperes	90	72	60	45	30
Speed (r.p.m.) ..	435	485	522	580	700

At the end of the test the resistance of the field winding was 0.175 *ohm and that of the armature winding* 0.285 *ohm. The corresponding temperatures of the windings were* 85° *C. and* 78° *C. Deduce the speeds for a machine temperature of* 60° *C.*

Solution.—The resistances at a temperature of 60° C. are calculated from the test resistances as follows :—

At a temperature of 85° C. the resistance of annealed copper changes by $\frac{1}{319.5}$ of its value at 85° C. for each ° C. difference of temperature, and at a temperature of 78° C. the change is $\frac{1}{312.5}$ of the value at 78° C. for each ° C. difference of temperature.

Hence the resistance of the field winding at 75° C. is :—

$$0.175-0.175\times\frac{25}{319.5}=0.175-0.0137$$
$$=0.1613 \text{ ohm}$$

and the resistance of the armature winding at 75° C. is :—

$$0.285-0.285\times\frac{18}{312.5}=0.285-0.0164$$
$$=0.2686 \text{ ohm.}$$

Therefore, the resistance of the motor at 75° C.=0.1613+0.2686=0.43 ohm (approx.).

The counter-e.m.f.'s are next calculated and the corrected speeds are obtained from formula (3). Thus :—

Amperes	90	72	60	45	30
Counter-e.m.f. (test) ..	178.6	187	192.4	199.3	206.2
Counter-e.m.f. (60° C.)	181.3	189	194.2	200.6	207.1
Speed, 60° C. (r.p.m.) ..	442	490	526	584	704

(2) *The full-load speed of a* 7½ *h.p. shunt-wound motor when cold* (20° *C.*) *is* 1150 *r.p.m., the input being* 60 *amp. at* 110 *volts. The cold resistances* (*at* 20° *C.*) *of the armature and field windings are* 0.12 *ohm and* 80 *ohms, respectively. A test taken with the motor cold at a constant load of* 60 *amp.* 110 *volts input, and varying excitation, gave the following results :*

Excitation (amp.)	1.375	1.2	1.0
Speed (r.p.m.)	1150	1172	1205

Calculate the full-load speed when the machine temperature is 60° *C.*

Solution.—The hot resistances (60° C.) are calculated as follows :—

The percentage resistance coefficient (from Table II) for 20° C. is 0.393 per cent. Hence the resistances at 60° C. will be (60−20)×0.393=15.7 per cent. greater than the cold resistances. Therefore :—

Armature resistance (60° C.)=1.157×0.12=0.139 ohm.

Field resistance (60° C.)=1.157×80=92.6 ohms.

Whence, the exciting current (hot)=110/92.6=1.19 amp.

TABLE IV.—AVERAGE VALUES OF EFFICIENCY AND POWER FACTOR FOR SMALL THREE-PHASE 50-CYCLE INDUCTION MOTORS (SQUIRREL-CAGE ROTORS).

Horse-power.	Synchronous Speed. (r.p.m.)	Number of poles.	Frame size.	Efficiency (per cent.). Full load.	¾ load.	½ load.	Power Factor (per cent.) Full load.	¾ load.	½ load.
½	1,500	4	A	81	81	79	79	72	60
½	1,000	6	B	81	80	78	70	61	47
1	1,500	4	A	81	81	79	80	74	61
1	1,000	6	B	82	82	80	71	62	48
2	1,500	4	B	85	85	83	83	77	65
2	1,000	6	C	82	82	80	78	70	56
3	1,500	4	C	84	84	82	87	82	71
3	1,000	6	D	83	83	81	80	72	58
5	1,500	4	D	85	85	83	89	85	76
5	1,000	6	E	86	86	84	83	77	65
5	750	8	G	85	85	83	77	69	56
10	1,500	4	F	88.5	88.5	87	89	85	76
10	1,000	6	H	87	87	86	87	82	72
10	750	8	J	86	86	84	80	73	60
20	1,500	4	J	89.5	89.5	88	91	87	80
20	1,000	6	K	89	89	88	88	84	74
20	750	8	L	89	89	88	85	79	68

TABLE V.—AVERAGE VALUES OF EFFICIENCY FOR SMALL THREE-PHASE 50-CYCLE INDUCTION MOTORS (SLIP-RING ROTORS).

Horse-power.	Synchronous Speed (r.p.m.).	Number of poles.	Frame Size.	Efficiency (per cent.). Full load.	¾ load.	½ load.	Power Factor (per cent.) Full load.	¾ load.	½ load.
2	1,000	6	C	75	75	73	74	67	52
3	1,500	4	C	81	81	80	83	78	68
3	1,000	6	D	80	80	78	75	68	53
5	1,500	4	D	84	84	83	84	79	69
5	1,000	6	E	84	84	83	80	73	62
5	750	8	G	84	84	83	72	65	53
10	1,500	4	F	89	89	88	84	80	70
10	1,000	6	H	87	87	86	82	76	65
10	750	8	J	87	87	86	75	69	57
20	1,500	4	J	89	89	88	88	84	76
20	1,000	6	K	90	90	89	83	78	67
20	750	8	L	90	90	89	79	72	60

If the cold-speed excitation characteristic is plotted, the cold speed corresponding to this excitation will be found to be 1173 r.p.m.

Hence the full-load speed hot

$$=1173\times\frac{\text{counter-e.m.f. (hot).}}{\text{counter-e.m.f. (cold).}}$$

$$=1173\times\frac{110-58.8\times0.139}{110-58.6\times0.12}$$

$$=1160 \text{ r.p.m.}$$

A.C. MOTORS.

Quantities Usually Involved with A.C. Motors.

The practical man is concerned chiefly with the quantities relating to the performance of A.C. motors, such as: Resistances of windings; temperature rise; efficiency; power factor; current input; speed; losses.

Resistances of Windings and Temperature Rise.

These are calculated by the same methods as explained in the section on D.C. motors.

Efficiency, Power Factor and Current Input.

The power input to an A.C. motor is calculated by dividing the output by the efficiency, just as for a D.C. motor. But the calculation of the current input requires a knowledge of the power factor; which, like the efficiency, is a particular quantity for every motor. The power factor depends upon the design of the motor, and for a given motor varies with the load. Typical average values of power factor and efficiency for small three-phase induction motors are given in Tables IV and V.

When the efficiency and power factor are known, the calculation of the current input corresponding to a given output is a simple operation. Thus, for a single-phase motor:—

Current input

$$=\frac{\text{power (watts) output}}{\text{efficiency}\times\text{power factor}\times\text{line voltage}}\quad\ldots(9)$$

and, for a three-phase motor:—

line current input

$$=\frac{\text{power (watts) output}}{1.73\times\text{efficiency}\times\text{power factor}\times\text{line voltage}}\quad\ldots.(10)$$

Current Input at Fractional Loads.

The current input at fractional loads cannot be calculated from the output and losses—as was the case with D.C. motors—because in the present case the power factor is involved, and this quantity varies with the load. Hence an approximate calculation of this current is only possible by assuming a value for the power factor.

Speed.

In induction motors the speed is independent of the supply voltage. The

TABLE VI.—SYNCHRONOUS SPEEDS FOR 50 CYCLES.

Number of poles ..	2	4	6	8	10	12
Synchronous Speed (r.p.m.) ..	3,000	1,500	1,000	750	600	500

no-load or synchronous speed is calculated from the formula :—

$$\text{Synchronous speed (r.p.m.)} = \frac{\text{Supply frequency (cycles per second)} \times 60}{\text{half number of poles}} \quad \ldots.(11)$$

Table VI gives the synchronous speeds for different numbers of poles and a supply frequency of 50 cycles per second.

The speed on load is slightly lower than the synchronous speed, the drop in speed being proportional to the load. The percentage drop in speed from no load to full load is called the percentage "slip." With a rotor of normal resistance the slip is about 5 per cent. for a 5 h.p. motor and about 3.5 per cent. for a 20 h.p. motor. Thus the full-load speed of a 5 h.p., 4-pole, 50-cycle motor is about $1500 \times (1-0.05) = 1425$ r.p.m., and the half-load speed is about $1500 \times (1-\frac{1}{2} \times 0.05) = 1462$ r.p.m.

Numerical Examples on Three-phase Induction Motors.

(1) *Calculate the full-load current input to a 5 h.p., 400-volt, 4-pole squirrel-cage motor.*

Solution.—From Table IV the full-load efficiency is 85 per cent., and the full-load power factor is 89 per cent.

Hence, from formula (10), the current is :

$$\frac{5 \times 746}{1.73 \times 0.85 \times 0.89 \times 400} = 7.14 \text{ amp.}$$

(2) *Calculate the full-load current input to a 10 h.p., 400-volt, 6-pole slip-ring motor.*

Solution.—From Table V the full-load efficiency is 87 per cent., and the full-load power factor is 82 per cent.

Hence, from formula (10), the current is :

$$\frac{10 \times 746}{1.73 \times 0.87 \times 0.82 \times 400} = 15.1 \text{ amp}$$

(3) *The full-load "slip" of a 20 h.p., 6-pole, 50-cycle motor is 3.5 per cent. What is the full-load speed? Also what is the speed at half load?*

Solution.—The synchronous speed, from Table VI, is 1000 r.p.m. Hence, the full-load speed

$$= 1000 \times (1-0.035) = 965 \text{ r.p.m.}$$

The slip at half-load is $\frac{1}{2} \times 3.5 = 1.75$ per cent. Whence, the speed at half-load

$$= 1000 \times (1-0.0175) = 982 \text{ r.p.m.}$$

Losses.

The losses in a three-phase induction motor comprise : (1) the constant "no-load" losses (consisting of the core loss, and the friction and windage losses) ; (2) the variable I^2R losses in the stator and rotor windings.

The I^2R losses can be calculated for the stator and slip-ring rotor windings when the resistances of these windings are known. If both of these windings are three-phase windings, and the resistances are measured between *any pair* of stator terminals or rotor slip rings, then the *total* I^2R loss in the respective winding is given by :—

$\frac{3}{2} \times$ (*line* current)$^2 \times$ measured resistance between terminals.

On the other hand, if the resistance *per phase* of the respective winding is known, the total I^2R loss is given by :—

$3 \times$ (*phase* current)$^2 \times$ resistance *per phase*.

Thus, in this case, a knowledge of the internal connection (star or delta) of the winding is required.

D.C. DYNAMOS.

Quantities Involved With D.C. Dynamos.

The quantities with which the practical man is chiefly concerned and may wish to calculate are : Resistances of windings ; temperature rise. Other quantities such as the flux, variation of voltage with load, efficiency, etc., cannot be calculated unless data of the machine are available. These calculations are associated more with the designing than the operating engineer.

Resistances of Windings and Temperature Rise.

These are calculated by the same methods as explained for D.C. motors.

Flux and Efficiency.

The flux is calculated by means of formula (5).

The efficiency is calculated from the output and losses in a manner similar to the calculation for a D.C. motor. In a dynamo the "no-load" losses are not independent of the load, as the excitation and iron losses increase with the load.

ESTIMATING FOR WIRING CONTRACTORS

By E. H. Freeman, M.I.E.E.

THE days when estimating the cost of an electric lighting installation consisted of a more or less careful inspection of a building or a set of plans followed by a rule of thumb assessment of the price "per point" are long past and estimating is now recognised as essentially a matter for careful measurement, to ascertain quantities of material, with equally careful weighing up of probable labour costs. The latter item must be based on experience, not only with similar past work, but also with the class of labour available and it is the wide differences in these conditions that involve the most difficult problems in deciding the probable cost of any particular scheme.

Price Per Point.

It will be as well to emphasise the extremely unsatisfactory features underlying the common habit of giving estimates on the basis of a "price per point." In the first place, there are wide divergences as to what constitutes a "point." It may be easy to define it when the "points" are all one-lamp outlets of similar size, each controlled by a separate switch, but beyond this simple unit there is no uniformity. It has been claimed in Scotland that a 5-light pendant is 5 "points," so that the contractor may find himself in the fortunate position of being paid for 5 points because a customer has decided on a 5-light pendant with 20-watt candle lamps, instead of a single unit fitting with one 100-watt lamp.

Common Variations.

This is an extreme case, but there are very wide differences of opinion as to the number of "points" for such common variations from the "one light—one switch" as the following :—

Light outlet controlled by two 2-way switches.

Two 1-light outlets, both controlled by one switch.

Light outlet controlled by two 2-way and an intermediate switch.

These are all common conditions even in a small house and these three groups of lights and switches might be considered by different persons as equal together to anywhere between four and eight times the wiring value of the "one light—one switch" point.

Apart from this difficulty the material and labour required for various "points" may differ widely even in a small installation and whilst figures "per point" may be used for very rough comparisons and at times, in repetition work, even for fairly reliable estimating, it would be, on the whole, best to abolish entirely any such method of comparison of one estimate with another.

Preliminary Study of Conditions.

The first step in estimating the cost of an installation is a careful study of the conditions. The installation may be of the contractor's own design, with no specification whatever except his own ideas as to what is required. This, of course, leaves him free to arrange his methods of wiring and all other details to suit his own views, but even in such conditions he will usually be obliged to adopt some standard such as I.E.E. rules, the local supply company's regulations or an insurance company's requirements.

Except in small contracts such conditions rarely apply and usually the contractor has to meet the more or less loose requirements of an architect or client, or the more or less fully defined conditions of a consulting engineer's specification. Even if the contractor is himself designing the scheme he will almost certainly be called on to give a fairly detailed description of his proposals and to be prepared to answer questions as to how he will meet this or that difficulty. Unless such problems have been faced previous to estimating, he may find himself unable to satisfy his customer, with a risk of losing the job or, alternatively, may find unexpected troubles in carrying out the work, with consequent loss of profit.

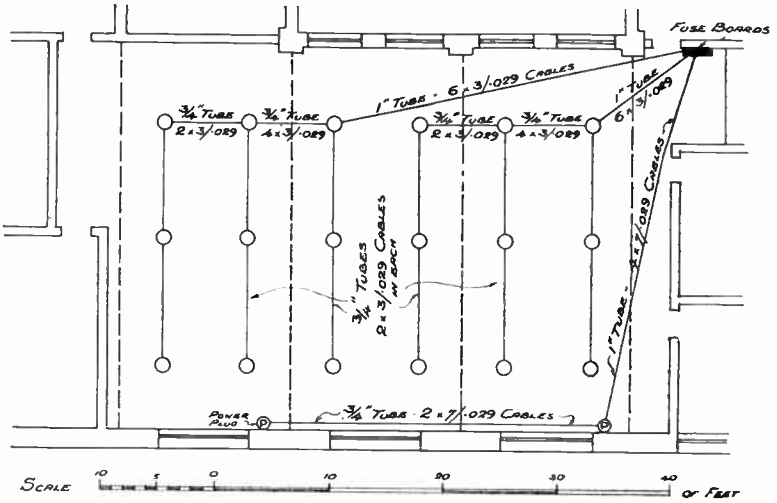


Fig. 1.—PLAN OF TYPICAL OFFICE AREA.

Layout of tubing for specification which allows tubes up to 1 inch diameter in floor, bunching up to three circuits in one tube, traps in floors.

Thickness of Screed as an Example.

For example, failure to ascertain the thickness of the screeding on a fireproof floor might be a serious matter. The estimator might assume he has ample thickness and can use 1 in. conduit, only to find that he must confine his runs to tubes not over ¾ in., resulting in a possible large increase in the cost of material and labour.

Another Example—Depth of Wood Joists.

As another example the depth of the wood joists in an ordinary wood floor may affect the cost. Notching of joists near the centre of a span is always undesirable, to say the least, but if the depth has been reduced to a minimum the architect may prohibit it entirely and then appreciable extra cost may be incurred in arranging all runs of conduit, either parallel with joists or close up to the walls.

Past Experience.

The above examples are very minor points, but they illustrate the need for careful consideration of all details, and this is particularly necessary in larger schemes and most of all in installations to be carried out to a consulting engineer's specification. Every such engineer, as well as every contractor, must, in the course of years, accumulate a wide range of information and experience as to what is the right method of carrying out a particular kind of work, but the opinions formed may differ very widely. A contractor, in preparing a scheme and estimate will, without realising it, base both on the opinions thus formed and much of the design and pricing up is carried out almost unconsciously.

Consulting Engineers' Specifications.

When he turns to a consulting engineer's scheme the details may be totally different from his usual standards and unless the specification is carefully studied serious errors may occur. Such questions as the grade of cable to be used; the minimum size of conduit permissible; the number of wires of various sizes allowed in a tube; the current that may be carried by any particular section, and so on, all constitute items that may affect the whole design of the scheme and its cost. Careless reading of the specification may result in a paragraph of two or three lines being overlooked and this may involve a very heavy extra cost. For example, that cables are to be 2,500-megohm C.M.A. grade, instead of the 600-megohm grade usually employed by the contractor, involves an extra cost for cables of about 8 per cent., which would represent a substantial sum on a large contract. Such an error might wipe out entirely the anticipated profit on this one item of the contract.

PLANNING THE ESTIMATE.

Having thoroughly mastered all the details of the scheme, the next step is to plan the estimate. It will not lead to reliable results if items are jotted down haphazard and some system must be adopted to ensure that all the work to be carried out is included in the estimate. A very convenient method is to form a mental picture of the completed installation and to trace the details of the materials required item by item. Thus the work will commence at the company's service and cables for meter connections must be provided—and, on second thoughts, possibly a sum to cover the company's charge for their service cables, which the contractor may be expected to include.

After the meters comes the main switch or circuit breaker and then, in turn: main fuse board, main cables, sub fuse boards and so on.

These details should be followed through for each separate section of the scheme and for each the different items required should be separately noted. Thus for the item of main cables there will be tubing, tube fittings and boxes of all descriptions and the actual cables, if the work is being carried out in conduit.

Following the sub-fuse boards come:—

Circuit wiring—tube, fittings, wire, etc.

Switches—of various types for different positions.

Plugs—also of various types.

Fittings and lamps—if these are included in the contract.

Each of these main headings may need dividing up into sub-sections, such as flush, surface, semi-recessed or watertight switches

A note should be made of every such item mentioned in the specification and the risk of any section of the work being overlooked will thus be eliminated.

Taking Out Quantities.

After the mental planning of the scheme and the recording of all items that need to be covered by the tender the measuring up of quantities will be necessary, and here again a mental diagram of the completed scheme will be of great advantage.

Items such as the main switch, fuse boards, local switches and plugs and fittings can all be priced up as regards cost of material without any great difficulty. The schedules and plans should give full details of such items and the total quantities of each can be ascertained without difficulty. The contractor will know the prices at which he can purchase most of them and if not he can obtain quotations from suitable manufacturers (or from those specified if such instructions are included in the specification). These items can thus easily be costed without much risk of error.

Measuring Up—Main Cables.

The contractor's real difficulties commence with the measuring up of quantities of cables and circuit wiring materials, i.e., broadly speaking, the tube and wire or their equivalent if other wiring systems than tubing are to be used. Main and sub-main cables will not involve much difficulty. The runs will be usually fairly clearly indicated from the plans and each main will consist of two wires in a single conduit unless bunching of mains is permitted. On three-wire or three-phase schemes there may be three or four wires if the distribution is not broken up into two-wire circuits at the main switchboard, but this will not occur except in large installations. The runs of such main cables can be settled on the plan and the measurements taken off without difficulty.

Allow for Wastage of Material.

Allowances must be made for wastage of material—5 to 10 per cent. on conduit may be lost in cutting random lengths as delivered by the makers—and cable quantities must include the short tails required for connecting up and slack at switches and fuse boards. Tube boxes should be estimated in detail as, particularly with the larger conduits, these are expensive items and averages are liable to involve substantial risk of error.

Circuit Wiring.

The measuring of the circuit wiring from the fuse boards to the lights and switches constitutes the most involved section of the estimate for the ordinary lighting installation and it is in this part of the estimate that there is the greatest risk of error. All the doubtful items that affect the methods of running the tubes (or other material used in the wiring system) play their part in complicating the problem of measuring up the circuit wiring materials. Tube runs (tube is used as an example, but the remarks apply to other systems) may need to run parallel with walls or may be taken on the shortest diagonal run ; tube sizes may be limited involving extra quantities ; wires may need to be drawn without the use of floor traps, involving looping down and up to every fitting outlet. A score of such minor problems must be considered and allowance made for each in the detailed planning of the wiring system, which should precede any attempt to measure the quantities.

Comparative Costs for Different Systems of Tubing.

Figs. 1 and 2 show in diagrammatic form two possible schemes for wiring a section of a building—the first with easy conditions and the other with more troublesome requirements. In the first case, tube sizes up to 1 in. are permissible and no conditions as to bunching circuits have been made, whilst floor traps are also allowed. In the second, tube sizes are limited by the thickness of the floor screeding to ¾ in. ; the specification strictly lays down that one only circuit may be run in any one tube ; that the minimum size of tube is ¾ in. and that floor traps are not permissible.

Difference in Cost of Two Systems.

The quantities of tube required for the two schemes, both of which provide wiring capacity for the same allowance of actual wires, and the costs of this material at prices ruling to-day work out as follows :—

Tube quantities for Fig. 1 :—110 ft. 1 in. tube ; 230 ft. ¾ in. tube.

Cost of material, including tube fittings, boxes, etc., £5 16s.

Tube quantities for Fig. 2 :—560 ft. ¾ in. tube.

Cost of material, including tube fittings, boxes, etc., £8 1s.

The second specification thus involves an extra cost on the tubing work for material only of 40 per cent. and the extra cost of labour in fixing will be still higher in proportion.

This example illustrates the importance of making sure that the specified conditions are kept in mind in designing the circuit wiring system.

Preparation of Wiring Plans.

The most satisfactory method of measuring up the quantities is to prepare actual diagrams on paper of the tube system required for any particular scheme of lighting and, as example, such a plan is shown for the tube lay-out suitable for the domestic installation the lighting for which was planned in an earlier article—see p. 789.

This plan shows the number of wires required in each section of the system and the size of tube in each case can then easily be ascertained from the " Capacity of Conduits " Table in the I.E.E. rules. The conditions in this case clearly preclude the use of floor traps and it has been assumed that conduits up to 1 in. diameter are possible in the floors and that up to three circuits can be bunched in one tube. The conduits must be run above the fireproof floors and be bent down into the fittings outlet boxes, which must be used as draw boxes.

The quantities of material required can

be taken off accurately from such a wiring plan and a very close measurement of what will be necessary for the whole of the circuit wiring thus ascertained. It is possible that such plans will not be necessary for every section of the work as some areas may be repeated elsewhere sufficiently closely for the quantities of one to be adopted, with suitable adjustments, for the other. It is advisable, however, to work the details out on some such basis for all but the simplest schemes.

Factory Designs.

These wiring diagrams will probably not be necessary in simpler schemes such as those in many factories. In such cases the switch controls are simplified: tube runs are carried straight along the walls or roofs and across tie bars and circuits are less complicated in every way. In addition the lighting plan almost forms in itself the wiring plan, but the principles involved are the same.

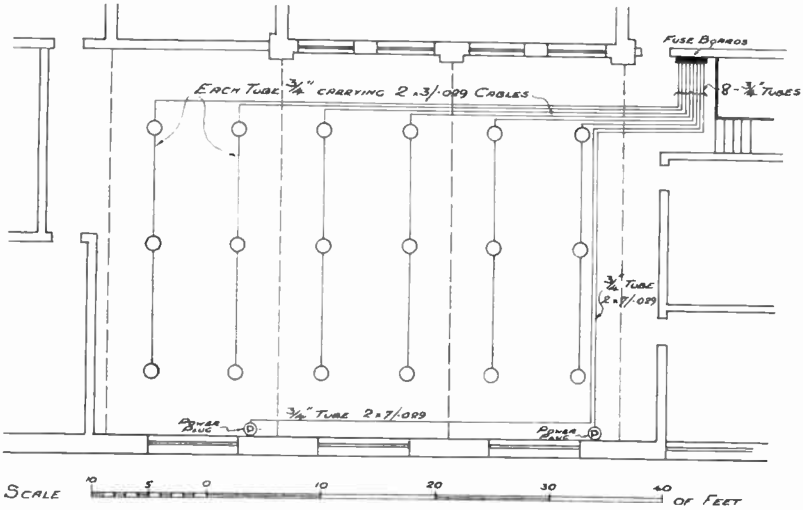


Fig. 2.—Plan of Typical Office Area.

Layout of tubing for specification which requires all tubes to be ¾ inch, not more than one circuit in one tube, no traps in floors allowed, tubes to be kept parallel to walls.

Domestic Wiring Schemes.

In small domestic installations also detailed plans may not be necessary, as the schemes are smaller and the whole wiring system can be mentally visualised and measured up without a detailed layout being prepared. This must largely depend on the experience of the estimator. One man may plan the whole scheme and take off his measurements without putting a line on paper, but usually this is not practicable for the inexperienced. It will be safer to prepare a detailed layout and to measure up from this in anything but very small contracts.

Scheduling the Quantities.

As the measurements of each section of the work are prepared it will be desirable—in fact, essential—to make a proper record of the quantities for each separate section. If this is not done it will be very difficult to check the figures should any doubt arise, or to correct them if variations are required, as is often necessary. A question as to the difference in cost for substituting brackets for pendants or of adding extra switches and so on, can easily be answered if the quantities for the area concerned can be picked out from the totals and adjusted up or down, but it may be difficult if there are no separate records available for the area in question.

Summarising the Estimate.

Having in this way arrived step by step at the total quantities of all the materials required, the full details of these should be set down ready for pricing up. Here again an orderly arrangement of the items is desirable, as it is then easy to see that everything is included.

The main cables, for example, might be set out in this form :—

	Rate per Unit Quantity	Total cost. £ s. d.
Ground Floor.		
20 ft. 1¼ in. conduit, heavy gauge, screwed, enamelled . .		
14 yds. 19/.044, 600 megohm, C.M.A.		
First Floor.		
32 ft. 1 in. conduit, heavy gauge, screwed, enamelled . .		
22 yds. 7/.064, 600 megohm, C.M.A.		
Third Floor.		
54 ft. 1 in. conduit, heavy gauge, screwed, enamelled . .		
40 yds. 7/.064, 600 megohm, C.M.A.		
Fourth Floor.		
76 ft. 1 in. conduit, heavy gauge, screwed, enamelled . .		
54 yds. 7/.064, 600 megohm, C.M.A.		

From such a list it will be easy to notice that the second floor mains have been omitted, whereas, if all the quantities had been totalled before pricing, such an error might be overlooked. A little extra paper and a few more calculations may be required, but the minimising of error is well worth these disadvantages.

Details of the tube fittings—draw boxes, bends and so forth—should, of course, be included in each case and also an allowance for saddles, extra sockets, screws, etc., but these have been omitted above for the sake of simplifying the example.

Approximate Checking.

Having completed the summary of the whole of the material it will be desirable briefly to check the quantities before proceeding to price up the cost and to estimate the labour required to fix the material.

Even a hurried glance down the summary will show whether all necessary items are included and would, for example, note the omission as above of mains for the second floor. Differences between lengths of conduit for successive floors should correspond to the heights of the floors and in this way another obvious error in the above figures would be seen, viz., that the measurement from third to fourth floor is shown as 22 ft. With a difference in measurement of 11 ft. per floor from first to third and 22 ft. from third to fourth an obvious error is indicated and can be corrected.

Checking Circuit Wiring.

A similar rough check can be made on the circuit wiring, but here more experience is necessary. Such experience will have provided a mental record of average quantities for similar installations and any wide variation would call for re-measuring or, at least, a reference back to the detailed figures to ensure that there was no error in copying or in adding totals.

It is not possible to give really reliable figures for such averages as conditions vary within wide limits, but for normal installations the following quantities may be taken as reasonable.

Tube Systems.
Domestic Installations—
  Small—18 to 20 ft. of tube per light outlet.
  Large—22 to 30 ft. of tube per light outlet.
Office Installations—
  Local Lighting—20 to 24 ft. of tube per light outlet.
  General Lighting—25 to 30 ft. of tube per light outlet.
School Installations—As offices.
Factories—Quantities vary too widely for averages to be safely assumed.

Twin Lead Systems.
Domestic Installations—
  Small—6 to 8 yds. twin conductor per light outlet.
  Large—8 to 10 yds. twin conductor per light outlet.
Office Installations—
  Local Lighting—8 to 10 yds. twin conductor per light outlet.
  General Lighting—10 to 12 yds. twin conductor per light outlet.

These figures for twin lead wiring would also apply to C.T.S. installations and they must be adjusted if single or triple conductors are used. Thus 2 yds. of triple conductor could be taken as equal to 3 yds. of twin conductor.

The figures are only very approximate and cannot be taken as reliable, as conditions vary so widely. For example, an extra foot in the height of a room must obviously add 1 ft. to the average quantity of tube for a " point " consisting of a light outlet and a switch. The estimating engineer will be well advised to collect

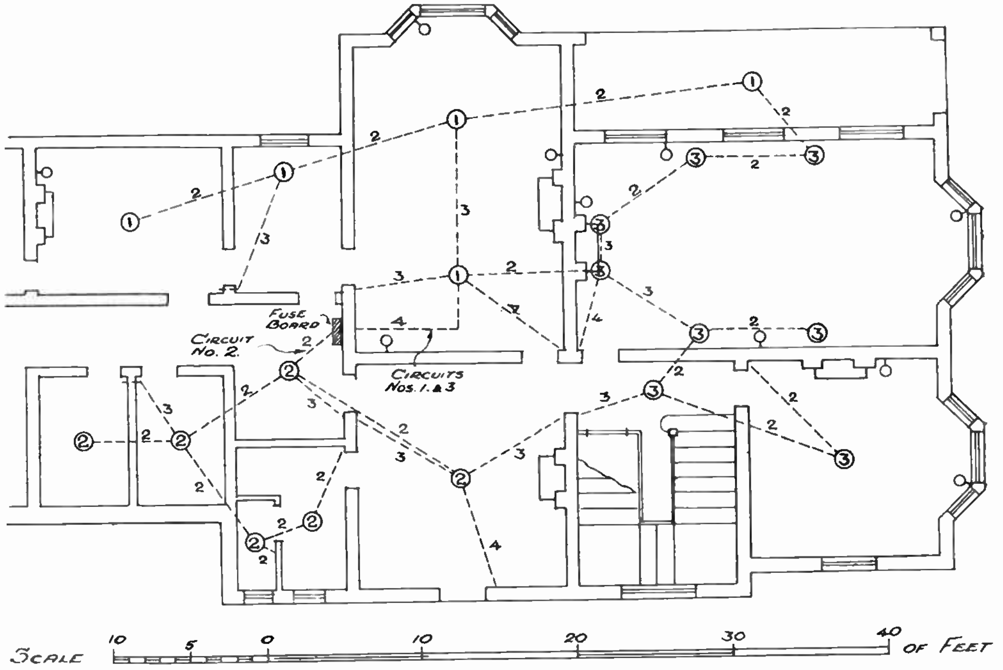


Fig. 3.—PLAN SHOWING TUBE AND CABLE RUNS FOR HOUSE. (SEE ARTICLE ON PAGE 789). Figures in circle show circuit to which points are connected. Dotted lines show runs of tube. Figures by dotted lines show number of wires in tube. Measurements can be taken direct from plan with vertical drop to switches and plugs added. Tubing for plugs not shown to simplify diagram.

the data for as many actual contracts as possible, not only for use in rough checking future estimates, but also to check accurately each actual contract with the estimate prepared beforehand.

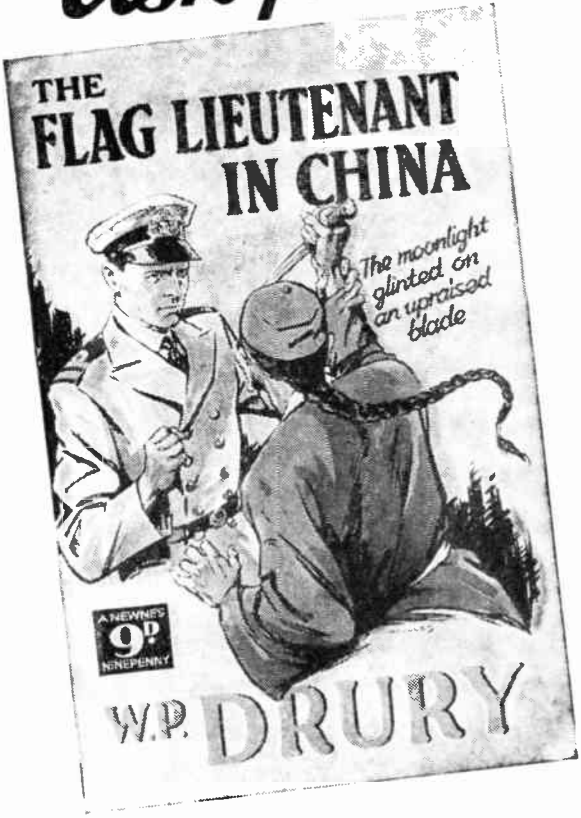
Cable Quantities.

A similar rough check on cable quantities should also be made. For 2-wire mains, if bunching is not allowed, the length of cable must obviously be twice the length of tube plus a small allowance for connecting up and for slack, and also allowance for the length of the tube fittings.

For circuit wiring it will be found that about 1 yd. of cable is required for each foot of tube. This again must depend on the extent to which bunching is allowed; the relative number of switches and light outlets; the quantity of 2-way and intermediate switches, and so on; but if there is any very marked difference from these relative quantities a careful checking of the measurements would be desirable.

LABOUR COSTS.

Whilst estimates of the material required to carry out an electrical installation can be prepared with very great accuracy and without much risk of error if proper care is taken in measuring the details, the position with regard to the prospective labour cost is much more problematical. Conditions vary on every item in every contract and every variation involves some doubt as to its effect on the time required to carry out the work. In addition, there is the human factor, involving the relative capacity of various men, and this varies according to the class of work. Thus one man may be expert in erecting tubing, but slow with lead-covered conductors, whilst the position is reversed with another man. Estimates based on the results obtained from the



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