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IMPORTANT ANNOUNCEMENT INSIDE THIS ISSUE

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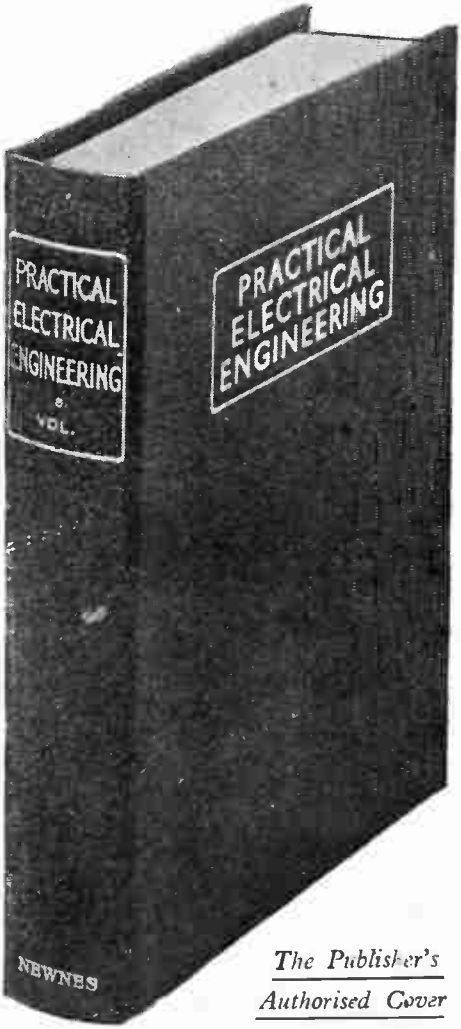

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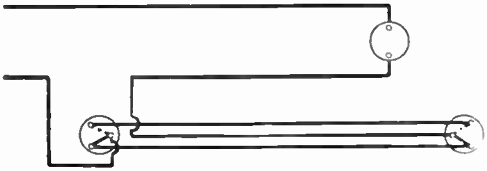
ERRATA FOR VOLS. I—V

P. 28. Insert this diagram in place of Fig. 12B.



P. 49. In Fig. 4, terminal 2 of the S.G. coil and the moving plates of the reaction condenser should be connected to L.T. negative and not to L.T. positive.

P. 51. In Fig. 7, the coils DBG and DBA should be transposed.

P. 52. In Fig. 9, the lead from terminal 1 of the S.G. coil should be connected to the grid leak side of the grid condenser, and not to the grid side.

P. 156. In Fig. 14, the mechanical parts of the crane were made by Messrs. Heywood, of Redditch.

P. 277. Figs. 7 and 8, " N " and " S " signs should be interchanged.

P. 338. Transpose the captions under Figs. 13 and 14.

P. 380. In Fig. 13, a .0003 coupling condenser from the H.F. choke should be connected direct to the anode of the valve and not to the H.T. side of the H.F. choke.

P. 513. Fig. 9. Positive connection of last condenser should be connected to H.T.2 and not H.T.1. This would not usually affect the working of the eliminator or the set to which it is connected because the decoupling condenser in the set would prevent any L.F. oscillation.

P. 517. Fig. 18. Reference letters B and C should be transposed.

P. 518. Col. 1, line 9. Should read 1-5,000 ohms fixed resistance.

P. 587. Fig. 9. For greater safety it is recommended that the ebonite adaptor should be provided with sockets instead of pins. The pins should then be mounted on the kettle.

P. 590. In Fig. 1, the 60/70 Hys. choke from which the loud-speaker lead is taken should be of the iron core type.

P. 593. In Fig. 2, the 50/70 Hys. pentode choke should be of the iron core type.

P. 703 and 706. Transpose captions under Figs. 11 and 13.

P. 1049. Fig. 3 is upside down. Last four lines of caption should read: " The top and bottom bearings are instantly removable by means of a bayonet catch."

P. 1061. Fig. 11 (upper half). The horizontal line in this figure indicates the mean value of the D.C. supply voltage.

P. 1176. Col. 1, line 13. " 20 feet " should be " 20 inches."

P. 1429. Col. 2, last line. " Thousandth " should be " millionth."

P. 1474. Fig. 11. Words " ON " and " OFF " should be transposed.

P. 1525. Fig. 1. The main switches should be on the live side, i.e., between the meters and the fuses.

P. 1547. Fig. 3 shows a weight-driven master frequency meter, and not the impulse driven types as described in the article.

P. 1716. Fig. 3, and p. 1719, Fig. 4. For wave-length (metres) read wave-length (mμ).

IMPORTANT ANNOUNCEMENT

With the approach of the final issue of PRACTICAL ELECTRICAL ENGINEERING, a large number of readers have written to the Editor asking that the Work should be continued in some form or another. In view of the exceptional interest which has been shown, he now has pleasure in announcing that the Publishers have decided to continue the Work in the form of a monthly Magazine, the first Number of which will be issued in August under the title of

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This section will interest Maintenance Engineers, and also Wiring Contractors responsible for the equipment of buildings of this type. An important sub-section will be that dealing with—

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are some of the items coming under this heading.

L NOTE.

Any suggestions which you care to send me in connection with the new Magazine will receive most careful consideration. Electrical Workshop Hints, Labour Saving Methods, etc., will be specially welcome, and all matter used will, of course, be paid for at our usual rates. Address your letters to The Editor, "The Practical Electrical Engineer," George Newnes, Ltd., 8-11, Southampton Street, Strand, W.C. 2.

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This will be of special interest to the Wireless Dealer. It will contain valuable ideas relating to "bread and butter" subjects such as—

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- Modern Methods of Fitting, Testing and Repairing Car Electrical Accessories of all kinds.

THE BUSINESS SIDE

The point of contact between the electrical engineer and the rest of the community is through the Business side. Every live man in the Industry should, therefore, keep himself in touch with Business developments. From time to time sections will, therefore, be devoted to such subjects.

ABOUT THE CONTRIBUTORS

The high standard which has been set in the present work will be continued in the Magazine. Here are the names of some of the well-known electrical engineers from whom contributions are expected for the early issues—

Kenelm Edgcumbe, M.I.E.E.
Professor Miles Walker, F.R.S., M.I.E.E.
A. T. Dover, M.I.E.E.
E. H. Freeman, M.I.E.E.
Sir Richard Tetley Glazebrook, D.Sc., F.R.S.
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the four figures of the number required are indicated to the operator by lighting one of the ten lamps in each of the four groups and thus illuminating the desired figures beneath a green glass sheet. The manual operator, therefore, is advised as to the connection required and does not enter or speak on the circuit.

Toll Exchanges.

These exchanges are junction centres in a large area and no subscribers' lines are connected to it. Their function is to link together exchanges not in direct connection with each other.

TRANSMISSION.

A telephone system is practically unlike everything else in that it must be designed as a whole, since any subscriber on the system must be able to speak to any other subscriber connected to a telephone system in any other part of the world.

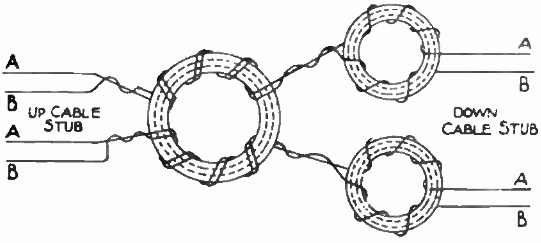

Fig. 30.—Loading Coils for a Circuit Carrying a Phantom.
(*Post Office Technical Pamphlets.*)

The Kingdom is covered by a large number of exchanges each of which may be regarded as a collecting point for the subscribers in its immediate neighbourhood. These subscribers must, of course, be able to speak to each other, and in addition must be able to speak to subscribers connected with the other exchanges; hence it will be clear that it is necessary that the various exchanges should be interconnected by junction or trunk circuits. The problem involved in design is chiefly one of economics.

Problems Involved.

If an exchange serves a comparatively large area, the average length of the subscriber's line increases, whereas by putting three or four exchanges in the same area the average length of the subscriber's line is reduced, but at the cost of junction circuits connecting the exchanges together. Then again, when the subscriber speaks to another town, the question arises as to whether the subscriber's line shall be made of thick wire, and the long connecting circuits of thinner wire, or vice versa. But what it is desired to emphasise is that the telephone system must be designed as a whole, and that when circuits are connected to the Continent via submarine cables, or are connected to America by radio circuits, complete international planning is necessary to secure that any combination of circuits shall be effective. This function is performed by the Comité Consultatif Internationale, known as the C.C.I.

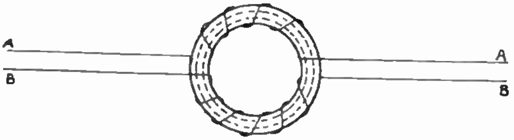

Fig. 29.—Arrangement of a Loading Coil.
(*Post Office Technical Pamphlets.*)

With a telephone connection between two points the transmitting telephone may be regarded as a dynamo or generator which delivers a certain amount of power to the telephone circuit, and at the distant end the receiver may be regarded as a form of motor which converts the electrical energy received into sound. As the length of the circuit connecting the two stations increases, the quantity of energy available at the receiving station becomes smaller, and it is the fact that, given any particular uniform type of telephone circuit, the decrease in the energy received follows the inverse of the compound interest law.

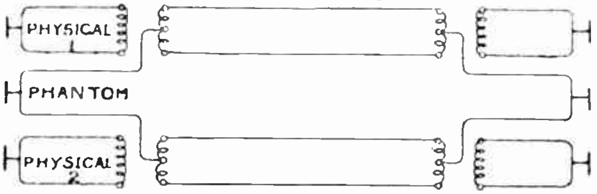

Fig. 31.—Superposed or Phantom Circuit.
(*Post Office Technical Pamphlets.*)

A

The expression connecting the current received I_r and the current sent out I_s is :—

$$I_r = I_s e^{-\beta l}$$

where e=2.71828.... (the base of natural logarithms) :—

β=attenuation constant
l=length of circuit.

The factors (βl) which determine the amount of energy received are the capacity, resistance, inductance, and leakage, of the circuit.

The complete expression for β is complicated, but if inductance and leakage are ignored

$$\beta = \sqrt{\tfrac{1}{2}\omega CR}$$

where $\omega = 2\pi \times$ frequency
C=capacity per mile in farads.
R=resistance per mile in farads.

For practical purposes ω is usually taken as 800 periods per second and 2π times this is approximately 5000.

It will be observed that since the frequency enters into the expression for the value of the attenuation constant, notes of different pitch will be unequally attenuated and it is indeed fortunate that so much distortion in received sound is possible before speech becomes unintelligible. Actually, inaudibility due to the weakness of received current supervenes before distortion becomes serious.

The capacity of an overhead circuit varies from .0075 mfd. to .01 mfd., whereas the value for a circuit in an underground cable is from .0625 mfd. to .066 mfd., i.e., from 6½ to over 8½ times that of an overhead circuit.

The resistance of a 200 lb. copper overhead circuit is 20 times that of the 10 lb. conductors used in many cables. Hence the attenuation in the latter cases is exceedingly large and it may be said that it is only by loading and the use of valve repeaters or amplifiers that the problem of long distance telephony on underground circuits has been solved.

Loading.

The addition of uniformly distributed inductance to a telephone line greatly reduces its attenuation. Continuous loading is chiefly used for submarine cables and consists in wrapping the copper conductors with a permalloy or other nickel-iron alloy tape, which adds about 144 mh. of inductance per mile.

Lumped or coil loading is more efficient and, as its name implies, consists in the addition of loading in lamps by inserting coils at strictly equal intervals along the cable. This spacing varies from .568 mile for music circuits, where the transmission of higher frequencies is essential, to 2.6 miles. The standard spacing is 2,000 yds. and the inductance coils used vary from 8 mh. with a resistance of .9 ohm to 250 mh. and 10.5 ohms.

The coils are toroidal in form and have a core composed of permalloy powder compressed into solid form and wound so that a current creates a magnetic flux as indicated by the dotted lines in Fig. 29. The requisite number of coils is enclosed in an iron case, which is then filled solid with insulating compound and the connections led out by short lengths of lead-covered cable. A large size of loading case may weigh as much as two tons.

The method of loading a pair of circuits which carries a phantom circuit is shown in Fig. 30. The additional coil is magnetized only when currents flow along the wires of each circuit in parallel.

Superposed Circuits.

A third circuit, termed a superposed or phantom circuit, can be obtained by the addition of transformers to two loops, as shown in Fig. 31. This circuit divides its current equally between the two wires of each loop and consequently does not affect the side or physical circuits provided that the wires are all of equal resistance, inductance, capacity and insulation resistance.

Repeaters.

In general, the efficiency of a telephone circuit can be greatly increased by loading, but this alone is quite inadequate for very long circuits. The discovery of the thermionic valve solved the problem and repeaters are introduced at 60 or 70 mile intervals. Since the valve amplifies in one direction only, and speech in both directions is required, an arrangement similar to a duplex telegraph circuit is required, but, fortunately, the balancing arrangements are fairly simple. When several repeaters are required in the circuit

Fig. 32.—LARGE DUCT ROUTE UNDER CONSTRUCTION.

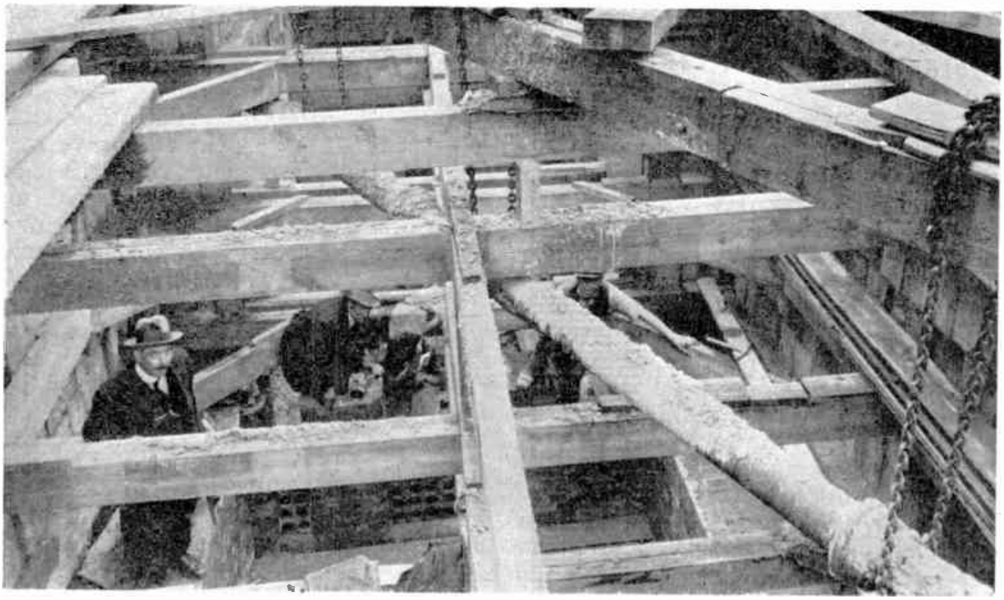

Fig. 33.—LARGE MANHOLE UNDER CONSTRUCTION.

four wires are employed, a pair for speech in each direction. The four wires are combined at each end.

Four-wire repeatered circuits are used for the longer trunk lines, whilst two-wire repeatered circuits are employed for shorter distances. By suitable amplification at the intermediate repeaters, the overall loss due to the transmission of speech currents along the line can be reduced to zero, a condition known as "zero speech."

Four-wire Circuits.

In four-wire circuits, the increased amplification necessary to give this condition increases the tendency of the circuit to sing or howl round the circuit composed of the two pairs of wires and the four-wire termination at each end of the line. This state of affairs is prevented by the inclusion of a 600-ohm resistance across the two-wire terminal whenever circuit conditions are such that the two-wire side would be disconnected.

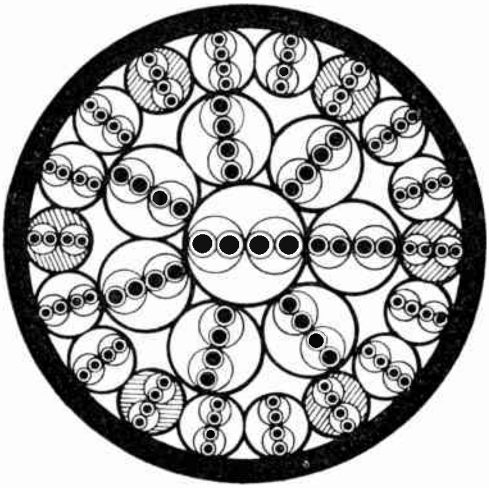

Fig. 34.—London-Liverpool Cable of 1913. 52 Pairs

Compare this with Fig. 34A, which shows a cable laid in 1930.

In two-wire working, the increase in amplification necessary to provide zero speech also increases the volume of the echo reflected back along the line from each repeater. To prevent this echo from reaching the talker's receiver, echo suppressors are associated with two-wire repeaters; it follows that the greater the amplification at each repeater, the greater the need for echo suppression.

The current received at the repeater is raised by means of the valve to its original value, and consequently it is possible to speak over practically any distance. There is, however, one defect which arises on a very long circuit, and that is the time which it takes the current to reach the distant end of the circuit, and it has been agreed that the circuit must be so designed that even in the longest case the delay shall not exceed a quarter of a second. When the delay exceeds this amount, the pause between the completion of a remark and the reply produces interference and misunderstanding.

LINE PLANT.

Heavy gauge copper conductors carried on overhead lines constitute the most efficient circuit for telephony and until the advent of the thermionic valve long-distance telephony was impracticable in any other way. Now, the decision as to whether overhead lines or underground cables shall be employed is solely one of economics. In general, all important long distance circuits are in cables, partly because the number of wires is now so great that special roadways or tracks would be necessary for the erection of huge overhead structures, but chiefly on account of the lower cost per circuit in a cable. Also there is the much lower cost of maintenance and greater immunity from interruptions or faults. Nevertheless, where a few circuits only are required, as from a rural exchange to its parent exchange the open wire line is still the only economic solution of the problem.

There is, however, one other condition which lies between the two extremes discussed needing consideration. The reorganisation of the trunk system on the basis of immediate connection with the wanted subscriber will necessitate the provision of large numbers of new trunks. Where practicable, these will be contained in aerial cables carried by poles along the roads. A simple form of repeater made up from mass-produced parts has been designed and in this way the cost per circuit of the new lines will be considerably reduced. Where several cables or cables of large diameter are required, there is no economic alternative to the use of underground conduits.

Exchange Subscribers' Circuits.

Turning now to the same problem where exchange subscribers' circuits are concerned, it will be at once appreciated that huge beds of aerial wires in a large town are not a practical proposition. But the cost per circuit in underground cables is actually much less. Large buildings in the centre of the city are served by underground cables taken into, or terminated on the outside, of the buildings and distributed thence to the various offices or floors by one-pair or other lead-covered cable which the needs demand.

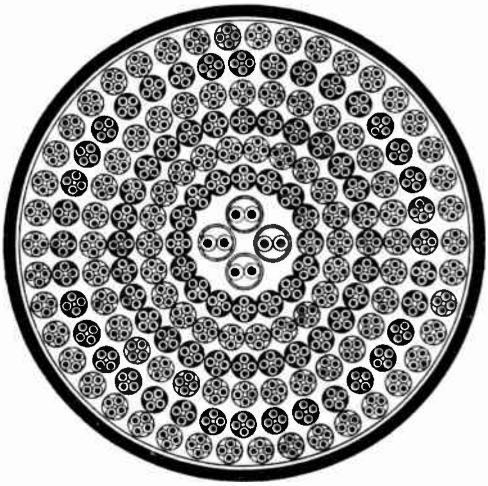

Fig. 34A.—London-Liverpool Cable Laid in 1930. 348 pairs of 25 lb. conductors with four pairs of 40 lb. conductors for the B.B.C. music circuits. See also Fig. 34.

In the suburbs quite a different condition occurs. Here the subscribers are sparsely scattered over a comparatively wide area and consequently the cost of laying underground conduits along both sides of every street and road is quite prohibitive. Hence underground cables are taken to distributing poles where the connection to the subscriber is made by open wires.

Underground Conduits.

In a large city, nests of ducts are provided beneath the roads, and where the number of conduits required is considerable it is usual to use earthenware ducts embedded in concrete, with manholes at 176-yd. intervals, in order that new cables may be drawn in and jointed as the growth of the system may require. It sometimes happens that these ducts have to pass beneath canals or other similar obstructions in the line of route, with the result that the ducts may be at a depth of 20 or 30 feet below the surface. The cost of providing the plant is so high that it is essential that adequate provision shall be made for a long period of years. If, however, the provision is on too lavish a scale, then the annual costs involved in unnecessary idle plant become excessive. It is, therefore, a problem in engineering economics to determine the precise amount of plant which shall be provided at the outset.

Types of Conduit.

A large number of conduits is necessary to provide for all the cables into a big exchange. The earthenware ducts used (18 in. in length) have a circular bore of $3\frac{1}{4}$ or $3\frac{1}{2}$ in., with an octagonal exterior. They are laid up in the desired formation layer by layer, on a reinforced concrete foundation and formed into a solid mass with Portland cement mortar. The concrete foundation is taken up the sides and over the top of the nest of ducts, thus forming a structure of enduring stability.

If the number of conduits to be provided is small, multiple way earthenware ducts are employed. A single conduit is met by the use of earthenware pipe with a bituminous joint.

Manholes and Joint Boxes.

The standard length between manholes or boxes is 176 yards, but it is often necessary to reduce this distance on account of changes in the direction of the route.

Manholes or boxes are provided for drawing the cables into the conduits and for the accommodation of the joints between the cable lengths. A route of two or three conduits needs only a comparatively small box with a lid of similar size. On the other hand a heavy route requires considerable space and in this

Fig. 35.—Pulling-in a Cable.

case the removable cover is only of sufficient size to permit men to enter the manhole. Manholes are generally built in reinforced concrete and contain a series of cantilevers or other similar supports for the cables with their joints.

Star Quad Cables.

In this, the latest type of cable, the four copper wires of each core are twisted together in one operation and so occupy the four corners of a square. Practically the whole of the insulation consists of paper and contrary to earlier practice, no attempt has been made to provide large air spaces. Stiffening of the paper tubes has resulted in the accurate and permanent centralisation of the conductors therein, whilst a central string upon which the four covered conductors are bedded secures symmetry in position. This extremely important feature of centralisation of the conductors within the paper tubes is secured either by the use of specially creased or corrugated surface paper wrappings or by a spiral whipping of string directly next the conductor, over which the insulating paper is tightly wrapped. The cable is extremely compact and the electrical characteristics are much more uniform

The requisite number of four-wire cores are assembled and covered with a seamless sheathing of lead. A cable of 127 quads (254 pairs) with conductors weighing 40 lb. per mile can be drawn into a conduit $3\frac{1}{4}$ in. in diameter.

A cable with 2,400 pairs with a diameter of less than 3 in. has been made, but in general the largest size generally employed is one with 1,200 pairs of $6\frac{1}{2}$ lb. conductors.

Pulling in and Jointing.

The lead-covered cables are drawn into the ducts by means of a petrol-driven winch, and jointing is carried out by hand as indicated in Fig. 35. A lead sleeve is then pulled over the completed joint and the cable is made air-tight by means of a plumber's wiped joint. When the cable section has been completed, it is tested for air-tightness by applying compressed air which has been dried by passing it through cylinders of calcium chloride to remove all traces of moisture. Gauges are added to the cable and any perceptible drop of pressure in 24 hours indicates that there is a defective joint, and this is located by smearing soap suds over the wiped joints.

Cable Balancing.

On long trunk or junction cables, particularly so on loaded cables, it is necessary to make a complete set of measurements of the wire to wire capacity values which depend on the distance between the wires, and also of the wire to earth capacity which depend on the distance of the wire from the cable sheath and from all the other wires in the cable. These measurements are made by a motor-van containing elaborate apparatus, and it is upon the results of these tests that a schedule is drawn up which directs the jointer how to connect the cores so that the unbalances shall be a minimum, and consequently that the finished cable shall be free from appreciable cross-talk. The technique of this process was devised by Post Office engineers, and is now in world-wide use.

Leakage Current Dangers.

Of all the dangers which menace telephone cables, leakage currents from tramways and power systems are the most serious. There are stray currents which enter the lead sheathing of telephone cables and which produce corrosion at the point where the current leaves the telephone cable. The remedy in this case is, of course, strict observance of the conditions laid down by the Electricity Commissioners for the operation of tramways in the first place, and secondly, the investigation of the distribution of these leakage currents and the provision of additional feeders on the tramway system to prevent differences of potential in the affected areas. In some cases a branch connection between the telephone cables and the return rail for the tramway system, is effective, but this remedy often introduces other difficulties at other points of the system, since the facilitation of the egress of current naturally increases the amount, and sometimes varies the distribution of leakage current in a way which it is more or less impossible to predict. Immediately the sheathing of a cable is eaten away by electrolytic action, sooner or later moisture enters, with the result that the cable is put out of action.

Detection, Location and Removal of Faults.

A technique has consequently arisen for the detection, location and removal of such faults. It is impossible here to indicate the details of these methods, but it may be said in general terms that in many cases the tests consist in Wheatstone Bridge tests taken from both ends of the circuit, and that it is possible to locate a fault of very high resistance with extraordinary accuracy

Cable Testing.

Yet another achievement of Post Office Engineers lies in the technique of cable fault localisation. To such perfection has this process been raised that any fault can now be located with extraordinary accuracy even in its incipient stages. It is possible here only to indicate that the methods used involve measurements from both ends of the cable and that it is possible to locate the precise position even of a badly soldered joint.

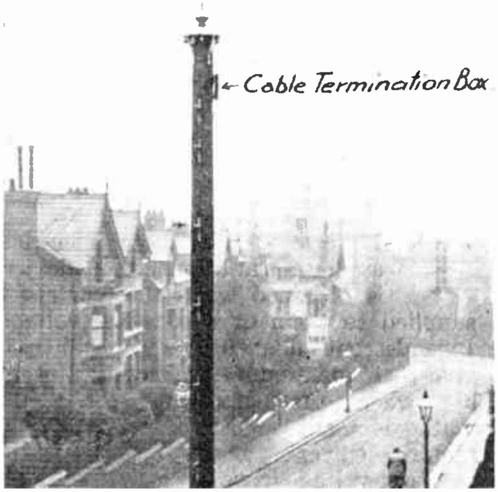

Fig. 36.—New Type of Pole For Taking Wires to Subscribers' Premises.

Distribution.

The underground cable system may be visualised as a number of vast trees where the main stem, which corresponds to the large cable leaving an exchange, divides into smaller branches and twigs. The problem involved in securing flexibility so as to avoid large quantities of spare or unusable wires owing to fixity of lay-out is an exceedingly difficult one. It is being met by providing auxiliary joints to meet rearrangements and in certain cases by teeing circuits to two or more distributing poles, but it cannot be said that the problem has yet been satisfactorily solved.

A recent development consists in the introduction of a pole from which pairs of insulated wires are taken to the subscribers' premises. This has had the effect of reducing the number of faults, and has also made a more sightly erection than is possible with a pole containing a number of arms, insulators, and open wires. This will certainly best be appreciated by Fig. 36.

References.

"Telephone," 2nd Edition, by T. E. Herbert and W. S. Procter. Vol. I (Pitman) in the press.

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THE TIRRILL VOLTAGE REGULATOR

NOTES ON OPERATION, CARE AND MAINTENANCE

By H. W. Johnson

THE best result from electrical appliances and consuming devices is obtained when the current is supplied to them at a constant voltage. Incandescent filament lamps will only give their maximum efficiency and useful life when the supply voltage is steady. Motors require current at a constant voltage in order that they will give a constant speed and maximum efficiency.

The maintenance of a steady supply voltage by a power station is therefore of primary importance.

Automatic Voltage Regulators.

It is almost impossible to maintain this voltage steady by hand regulation and even by using expensive specially designed generators, owing to the fluctuating nature of the demand on the supply mains. Automatic voltage regulators are now installed in most power stations to maintain a steady supply voltage. The use of these regulators saves considerable labour which is entailed by hand regulation and also allows of the use of cheaper generators. One of the best automatic voltage regulators, which is in extensive use, is the Tirrill regulator, which is patented and manufactured by the British Thomson Houston Company, Ltd., of Rugby, England. This regulator was introduced by Mr. Tirrill and was one of the first successful vibrating contact regulators to be used. It is made in two distinct types; one which is suitable for self-excited dynamos and the other for separately excited dynamos. Both types are made for direct and alternating current.

The regulators for direct current are designated type T.D., whilst for alternating current they are known as type T.A. regulators.

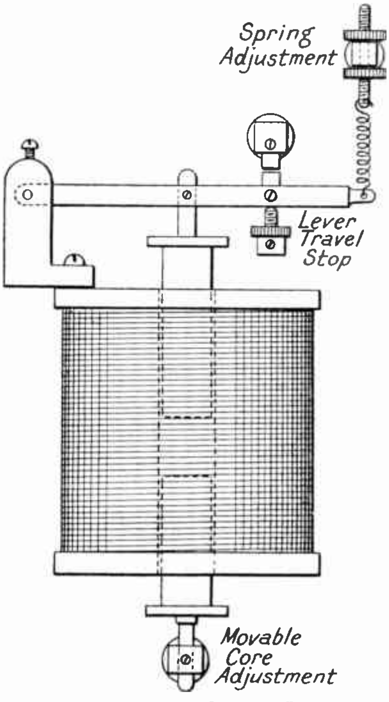

Fig. 1.—The Main Control Magnet and Pivoted Lever of a Type T.D. Regulator.

The magnet winding is provided with an iron core, the upper end of which is attached to the pivoted lever. The length of the movable core which is inside the lower end of the winding may be adjusted. The pull of the spring on the pivoted lever is adjusted by turning the knurled nuts, and the downward travel of the lever is limited with the adjustable screwed stop.

The T.D. Regulator for Self-excited Dynamos.

The instrument consists essentially of (1) A main control magnet, which is connected across the circuit where a constant voltage is to be maintained. (2) A differentially wound relay magnet which operates on the field magnet winding rheostat of the dynamo. (3) The main contacts which are actuated by the main control magnet and (4) the relay contacts actuated by the differentially wound relay magnet.

The Main Control Magnet.

The magnet is provided with an adjustable core at its lower end and a movable core above. The movable core is connected

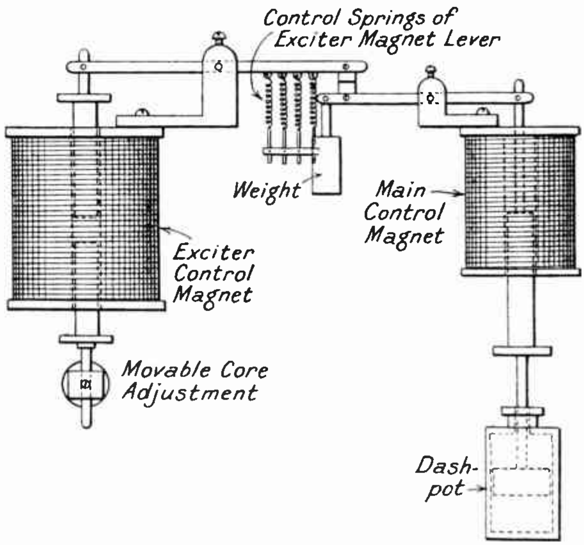

Fig. 2.—THE EXCITER AND MAIN CONTROL MAGNET OF A TYPE T.A. REGULATOR WITH THEIR RESPECTIVE PIVOTED LEVERS.

The pull on the core of the main control magnet is balanced by a fixed weight, and its motion damped with a dash pot. The exciter control magnet has its upper core attached to the pivoted lever. The pull on the core is balanced by the force exercised by the control springs. The length of the movable core inside the lower end of the exciter magnet winding may be adjusted.

to a horizontal lever which is pivoted at one end.

The Main Contacts.

The lower contact is fixed in the upper face of the pivoted lever, and fixed immediately above to a fixed stud on the regulator panel, is the upper contact. A spring connected to the free end of the lever pulls the contacts together when the downward pull on the lever by the movable core of the main control magnet is overcome. The pull of the spring may be adjusted within limits, and an adjustable stop limits the downward travel of the lever.

The Differentially Wound Relay Magnet.

The U-shaped relay core is provided with a magnet winding on each limb. One winding is connected directly across the terminals of the dynamo and the other is connected in parallel with it, when the main contacts are closed. The windings are identical, but when energised produce magnetic fluxes which are in opposite directions, and therefore neutralise each other.

The core of the relay when magnetised, will attract a pivoted iron armature fixed immediately above it. When the core is demagnetised, the armature is pulled away from it with a spring whose pull can be adjusted with a screw fitted in the suspension pillar of the spring.

The Relay Contacts.

The lower relay contact is fixed at the free end of the armature on its upper surface, and is pulled by the spring on to the upper contact, which is fixed to a pillar immediately above the lower contact.

The relay contacts open and close the shunt circuit of the dynamo and are protected from damage with a condenser of suitable capacity connected across them.

HOW THE REGULATOR WORKS

When the voltage of the supply

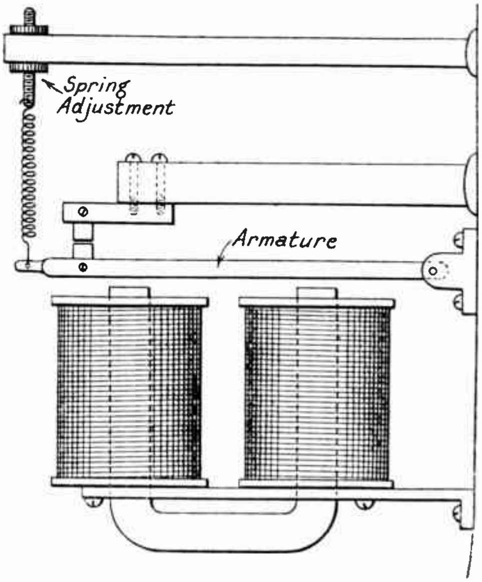

Fig. 3.—THE DIFFERENTIALLY WOUND RELAY AND PIVOTED IRON ARMATURE OF A TYPE T.D. REGULATOR.

from the dynamos falls below the normal the current through the main control magnet winding falls and therefore the pull on the movable core is reduced. The pull of the spring on the pivoted lever now closes the main contacts and the circuit of the second winding of the differentially wound relay is completed. The flux produced by this winding demagnetises the core of the relay and the attraction between the core and the pivoted iron armature now ceases. The pull of the spring on this armature now closes the relay contacts which short-circuit the shunt winding rheostat of the dynamo. The voltage of the dynamo now rises, but is prevented from rising above the normal value by the current in the main control magnet, whose attraction on the core fixed to the pivoted lever overcomes the pull of the spring on the lever, and the main contacts open. The core of the relay now attracts the pivoted iron armature, due to the second winding of the relay being de-energised, and overcomes the pull of the spring on the lever causing the relay contacts to open and putting the rheostat in circuit again with the shunt winding of the dynamo.

Sensitiveness of the Regulator.

Owing to the lightness of the moving parts there is practically no time lag in their operation, the contacts being in a constant state of vibration, and thus the voltage of the dynamo is kept within very close limits. The field winding rheostat of the dynamo is set so as to maintain about 60 per cent. of the normal voltage.

The T.A. Regulator for Separately Excited Dynamos.

This regulator differs from that of the T.D. type in that it has an additional control magnet whose windings are energised from the exciter of the dynamo. The main contacts are actuated by two levers. The lower contact is fixed on the upper surface of one end of the lever of the main control magnet, and the upper contact to the lower surface at one end of the lever of the exciter control magnet. Both of these levers are pivoted about their centres. The movement of the main control magnet lever is damped with a dash pot.

The main control magnet is so made that for a given voltage the pull on the lever is independent of the position of the core relative to the solenoid. A weight is fixed on the end of this lever to balance the pull, so that to keep a constant voltage, the force balancing the pull must be constant. The pull exerted by the exciter control magnet on its lever is balanced by springs.

The Regulator in Action.

When the voltage of the dynamo is decreased the lever of the main control magnet will tend to rotate in a clockwise direction, and if increased, in a counter clockwise direction.

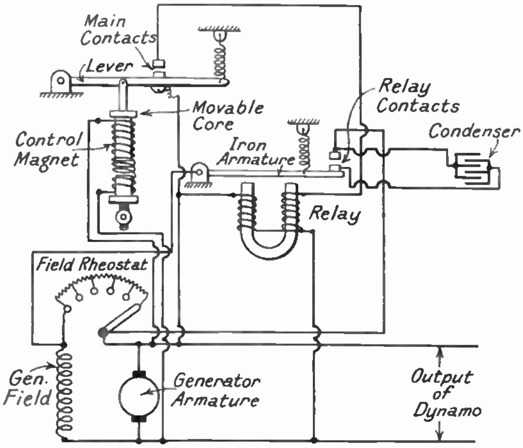

Fig. 4.—Simple Diagrammatic Connections of Type T.D. Regulator Connected to a Shunt Wound Dynamo.

If the voltage of the dynamo falls, then the main contacts will close. The relay contacts will now close through the action of the relay coils, and the rheostat in circuit with the exciter field magnet winding will be short-circuited.

The exciter voltage will now rise, until the dynamo field is strong enough to raise the dynamo voltage sufficiently to restore equilibrium in the main control lever. The exciter voltage continues to increase by a small amount and the pull of the exciter control magnet causes the lever to rotate in a counter clockwise direction, until the main contacts are open. Directly the main contacts open, the relay contacts open, and insert resistance in the field magnet winding circuit of the exciter. This type of regulator is more sensitive than the T.D. type, and because it operates on the exciter field rheostat and not on the dynamo, the losses are small.

When the regulator is used with A.C. dynamos, the main control coil is usually connected through a potential transformer to the terminals of the dynamo, or to the point in the circuit at which it is desired to maintain a constant voltage.

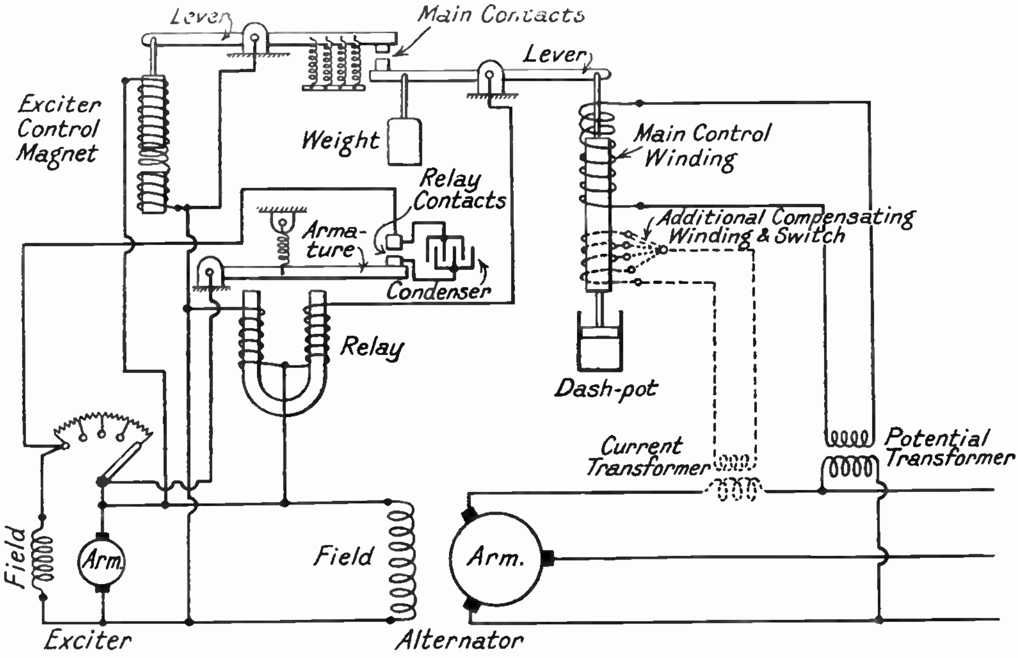

Fig. 5.—Simple Diagrammatic Connections of Type T.A. Regulator Connected to a Three-phase Alternator.

Simultaneous Operation of Tirrill Regulators.

When it is desired to use regulators for each of several A.C. dynamos which feed common bus bars, the main control coil is fitted with an additional winding whose turns can be altered with a regulating switch. The winding is energised from the secondary terminals of a current transformer. The primary winding of the transformer is connected in the phase not connected to the potential transformer, which operates the main winding of the magnet.

The effect of this additional winding is to reduce the excitation of an over excited dynamo, and to increase that of an under excited dynamo, thus preventing circulating current between the dynamos.

Tirrill Regulators Used to Maintain a Constant Load.

Tirrill regulators may be used to maintain a constant load on a dynamo which is used in conjunction with an automatic reversible booster used in connection with a battery of accumulators, for dealing with widely fluctuating loads.

AUXILIARY APPARATUS USED WITH TIRRILL REGULATORS.

High and Low Voltage Cut-outs.

If there is a breakdown on any part of the generating plant or the regulator equipment, the regulator is cut out of circuit with the high and low voltage cut-out, and at the same time a portion of the field rheostat is short-circuited, so as to give approximately normal voltage at the dynamo terminals.

The cut-outs are operated with a control coil which is connected in series with the main control magnet coil of the regulator.

The iron core of the control coil is suspended inside the winding from springs. A pivoted lever which is fitted with a contact, is attached to the upper end of the core, whilst above and below the contact on the lever fixed contacts are placed.

The Operation of the Cut-out.

When the winding of the control coil is energised the pull on the lever is opposed by the suspension springs, which are adjusted to keep the contact on the lever midway between the upper and lower fixed contacts.

If the voltage of the dynamo rises or falls beyond the limits for which the control coil is set, the contact on the lever bears on either the upper or lower fixed contact and the cut-out solenoid circuit is completed. When the cut-out solenoid coil is energised, a catch on the cut-out switch is tripped, and the regulator is cut out of circuit, and at the same time a portion of the field rheostat is short circuited.

Resistance Boxes.

The magnet coils of Tirrill regulators are designed for only a small voltage and it is necessary to provide a suitable resistance to be connected in series with them.

The resistance is mounted in a ventilated metal case which is fitted at the back of the regulator panel.

Fixing Tirrill Regulators.

The regulators with their auxiliary apparatus are mounted on black enamelled slate bases and may be fixed on the front of switchboard panels as separate instruments, or the separate parts may be mounted directly on the panels. In some cases it may be desired to mount the regulator base on iron brackets at either end of the switchboard; this method is not recommended.

A space of at least 40 inches should be allowed between the floor and the bottom of the regulator so that it is protected from damage when sweeping or cleaning the floor.

Cleaning and Maintenance.

The Tirrill regulator when it is once installed requires very little attention. The glass dust proof case in which the regulator is placed should only be opened when it is necessary to clean the relay contacts.

The contacts are cleaned occasionally with a strip of 00 glass-paper.

The strip is doubled longitudinally and placed between the contacts so that each contact is cleaned by the prepared surface of the glass-paper when it is pulled backwards and forwards in a horizontal direction. Remove any dust from the parts with a soft clean cloth. Examine carefully the flexible connections to the pivoted levers, and make sure they are tight. The bearings of the levers may be lubricated with a trace of clock oil.

Examine the settings of the various control springs and tighten up any nuts which may have worked loose.

The travel of the vibrating contacts should be $\frac{1}{32}$ of an inch, and it should be tested with a gauge for being correct.

The settings should not be altered except under the supervision of the B.T.H. Company.

PARTICULAR ATTENTION should be taken to prevent any dust being raised in the immediate vicinity of the regulator when the glass case of the regulator is open.

FAULT LOCATION IN ELECTRIC CABLES

By P. B. Addison, A.M.I.E.E.

ALTHOUGH the localisation of certain types of faults still presents some difficulty, so much progress has been made of recent years that the average fault can now be located with great accuracy. The cost of a cable breakdown will largely depend upon the accuracy of the location of the fault, and in view of the high cost of modern high voltage cable joints, indiscriminate opening of joints and cable cutting can only be justified under extreme conditions. The various methods that will be described are those that have been successfully used for the location of faults on large power transmission systems for many years, although it is not claimed that they are the only ones that can be applied.

Cause of Faults.

When once cables are buried in the ground, they are subject to unseen destructive forces other than electrical stresses which cause them to break down. These may be summarised in the following order :—

(*a*) Vibration.
(*b*) Subsidences and ground movement.
(*c*) Electrolysis.
(*d*) External damage.
(*e*) Faulty manufacture and workmanship.

Experience has shown that the greater percentage of faults occur through vibration, subsidences and earth movements. Cables may break down from precisely the same cause but the resultant fault will be entirely different ; in other words, a cable route subject to subsidence trouble may at one time affect a joint and another, buckle the cable.

Instruments.

Instruments for fault location should be robust and portable. As the tests carried out for fault location are "null" methods, the instruments do not depend so much on their dead accuracy as their sensitivity. The following list is suggested as likely to meet the requirements of the low-voltage tests that will be described :—

(*a*) Sensitive galvanometer.
(*b*) "Wheatstone bridge" and "slide wire" bridge.
(*c*) Standard condenser.
(*d*) High insulation charge and discharge key.
(*e*) Battery with intermediate tappings (about 100 volts).
(*f*) Millivoltmeter and ammeter.

Galvanometer.

In the choice, for fault localisation, a galvanometer with a short period has many advantages, one being that observations may be taken rapidly while the conditions of working are less liable to change during the test, although the sensitivity is not so high as one having a longer period. To secure a maximum speed and ease of working, the galvanometer should be critically damped. For measuring high resistance use a high resistance galvanometer; when measuring very small E.M.F.'s use a low resistance galvanometer. To obtain reliable readings, the moving system of a galvanometer should be shielded from external fields.

Wheatstone Bridge.

A Wheatstone bridge with a wide range of adjustment for loop testing. The total resistance of the rheostat arm should cover a wide range, say from 0.01 ohm to 10,000 ohms and so arranged that manipulation is simple, and the instrument capable of use by an inexperienced person. The ratios should have values of not less than 1,000 ohms in ranges of 1, 10, 100 and 1,000 ohms.

Slide Wire Bridge.

In portable form provided with a graduated scale.

Standard Condenser.

For the purposes of capacity measurements, a standard condenser in the order of .5 microfarad is necessary.

Key.

A highly insulated two-way key for capacity charge and discharge.

Millivoltmeter and Ammeter

with variable resistance capable of fine adjustment.

Battery.

A testing battery of not less than 100 volts with intermediate tappings.

These instruments are only suitable for low pressure tests.

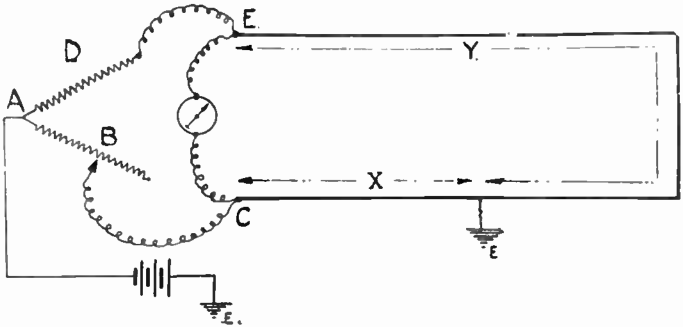

Fig. 1.—Connections for " Murray " Loop Test.

METHOD OF PROCEDURE IN LOCATING FAULTS.

Before an attempt is made to locate a fault, it is very essential to ascertain its exact nature and the following method of procedure might be suggested :—

After the cable has been put out of circuit, it should be permanently isolated from all live parts and discharged to " earth." A very careful insulation resistance test both to " earth " and between conductors should then be made and very carefully noted. The result of this test will have an important bearing on the method of localisation to be adopted. From this test the cable may appear sound, in which case, the conductors should be checked for continuity. The insulation resistance may be high and the conductivity sound, yet it trips out of circuit immediately it is switched in. The insulation resistance under these conditions may be too high for localisation and a fault of this description would require the application of special methods which will be described later to locate it. This type of fault is now frequently met with, due to the use of liquid and semi-liquid oils and compounds.

Switching in a faulty cable should be avoided wherever possible, owing to risk of damage to power station plant and transformers.

When a cable is found suitable for a location test, check the resistance of the conductors by measuring their resistance with a " bridge " and compare the result with a table of standard resistances. Too much emphasis cannot be placed upon the importance of this, for, should the conductors be fractured, it is likely that misleading results will be obtained.

Methods of Location.

Generally speaking, two types of faults are met with :—

(*a*) " Earthed " or " short-circuited " conductors.

(*b*) Open circuits.

The " Murray " Loop Test.

This test is applied when one or more conductors of a cable have broken down to " earth " or " sheath " where a healthy conductor is available for forming a loop. Ideal conditions for a test of this description are for the resistance of the fault to be low and the insulation resistance of the healthy conductor forming the loop to be high. With such conditions the results obtained by this method are very accurate. It may be explained for the guidance of an inexperienced person, that the healthy conductor having an insulation resistance value of 1 megohm would be considered good for the purpose of locating a fault in the order of 10,000 ohms to "earth." The practical arrangements of this test are shown in Fig. 1.

EC = Total length of loop (twice the route length).
X = Resistance from "C" to the fault.
Y = Resistance from "E" to the fault.
AC = Rheostat arm of "bridge."
AE = Fixed or proportional arm of "bridge."

AC is adjusted until equilibrium is produced.

Formula.

Distance of fault X from C = Length of loop $\times \frac{B}{D + B}$ i.e., Length of loop is Route length × 2.

Example.

A cable 1,000 yards long having one of its conductors "earthed" is looped at the distant end to a healthy conductor as shown in Fig. 1. The resistance arm "B" of the "bridge" is adjusted until equilibrium in the galvo. is obtained the reading being 50 ohms with the proportional arm "D" set at 1,000 ohms; then:—

Distance of fault X from "C"

$$= \frac{2,000 \times 50}{1,000 + 50} = 95.25 \text{ yards.}$$

It will be noticed that double test leads are used from the cable ends. There is a great advantage in this, as it permits of small leads being used of any length that may be carried to inaccessible test positions, thus allowing the test to be carried out in the most suitable place in comfort without any account being taken of them as they are not included in the test.

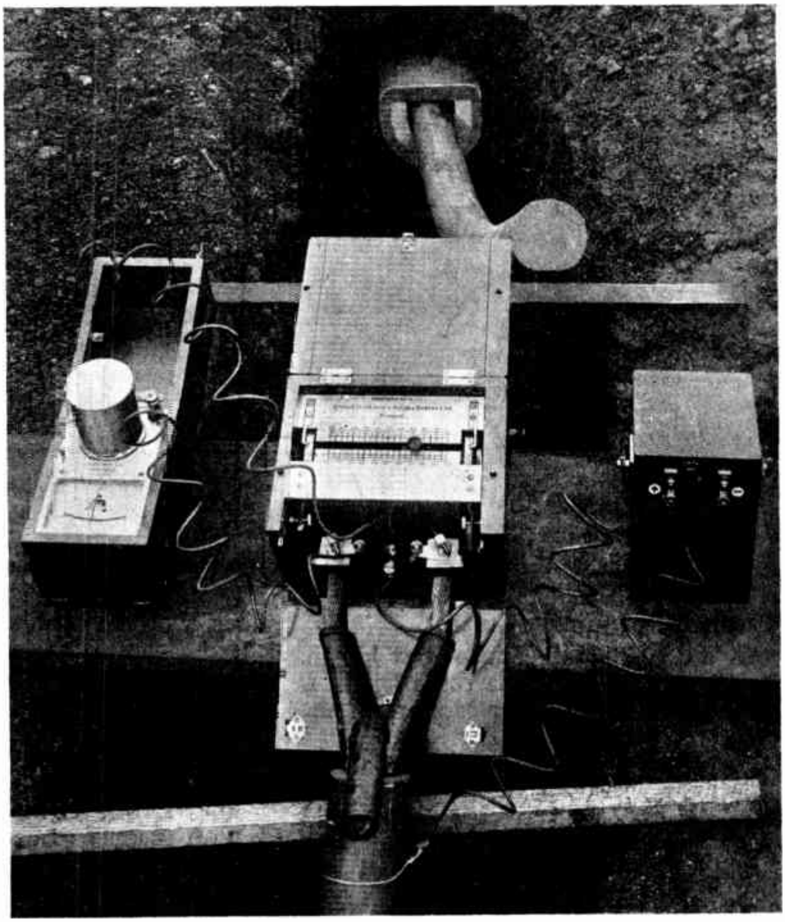
Fig. 2.—A PORTABLE SLIDE-WIRE BRIDGE IN ACTION.

Use as High Resistance as Possible.

In making a test of this kind, it is advisable to use as high resistance as possible in "B" and "D" because the greater these resistances, the greater will be the range of adjustment. As the fault is directly in circuit with the battery, if the resistance be large, the employment of high battery power is inevitable. The best conditions for making the "Murray" loop test is to make "D" as high as is necessary to obtain the required range of adjustment in "B," as "B" must be adjustable to a fraction of a unit, hence sufficient battery power must be employed to obtain a perceptible deflection of the galvanometer needle where "B" is one unit, or a fraction of a unit, out of exact adjustment.

Although the loop test avoids errors due to earth currents, it does not avoid errors due to cable currents, that is to say, currents set up by chemical action at the fault itself; this action causes a current to flow in opposite directions through the branches of the cable on either side of the fault; in other words, causes a current to circulate in the loop. This current, although weak, may be sufficient to cause slight errors.

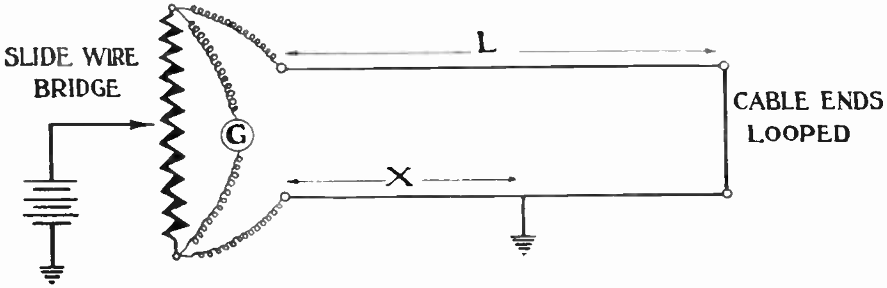

Fig. 3.—Slide-wire Bridge Connections for "Murray" Loop Test.

Calculation of Testing Lengths.

In ascertaining the loop test length, it will only be twice the route length if all the conductors under test are of the same sectional area. For example, a faulty cable is of 0.1 sq. inch and the return cable used for the loop is 0.15 sq. inch, the route length being 1,000 yards, then the total length of the loop would be :—

$$1{,}000 \text{ yds.} + \left(\frac{0.1 \text{ sq. in.}}{0.15 \text{ sq. in.}} \times 1{,}000 \text{ yds.}\right)$$

= 1,666 yds. In other words, if the cable making up the loop is of greater section than the faulty one, its equivalent length will be proportionately less than the route length and vice versa.

Slide-wire Method.

This method for making tests on the "Murray" loop principle is very widely used and many excellent instruments are made up in portable form, usually consisting of a rotating drum instead of the Wheatstone bridge, to which is attached a sliding contact connected to a battery. A galvo. is connected across the ends of the slide-wire. This sliding contact is adjusted by sliding it along the wire until a perfect balance on the galvo. is obtained. A pointer is attached to the sliding contact that passes over a graduated scale divided into as many as 10,000 parts. On low resistance faults and comparatively short cables it is capable of great accuracy, but on faults of high resistance or long cables it is not so accurate.

Fig. 3 shows the slide-wire bridge connections for the "Murray" loop test. The ratio $X/_2L$ as a percentage is given directly on the localiser scale, "X" being the distance to the fault and "L" the route length of the cable.

Another Application of the "Murray" Loop Test.

A further application of this method of testing is when the nature of the fault is such that no available good conductor can be got in the faulty cable itself for completing the loop, and some independent or adjacent cable has to be used. It sometimes happens that all conductors of a cable become "earthed" or "short-circuited." In a case of this kind, some method of utilising an adjacent cable has to be adopted. A pilot or telephone cable is a very good medium for the purpose, either of which can be used. As the sectional area of a cable of this description would in most cases be much smaller and therefore the resistance greater than that of a power or lighting cable, the equivalent lengths would have to be taken into consideration. In order to avoid long calculations, use is made of two of the healthy conductors instead of one. Both are connected to the faulty cable at the distant end, whilst at the testing end, one is connected directly to the galvanometer and the other to the "bridge" arm. The resistance of the conductor connected to the "bridge" is added to the resistance of the arm in the formula when calculating the fault distance. Fig. 4 shows the connections of the test :—

AB = Faulty cable with all conductors earthed.
R = Variable resistance arm of bridge.
S = Fixed resistance arm of bridge.
T = Resistance of telephone wire.
t = Galvo. lead.

Formula.

Distance of fault X = Route length

$$\times \frac{R}{S + R + T}$$

(from A).

This method will be found extremely valuable for locating many faults on auxiliary cables, such as telephone and pilot cables, by reversing the order and using the larger cable as the good conductors of the loop and one or more of the smaller ones as the faulty conductor. Other tests will be very readily thought out and applied from this method.

Example of Actual Test on a 20 kV. Cable.

A 20 kV. cable 10,972 yards long broke down and upon being tested was found with all three conductors "earthed" and also two of which were fractured. There was a four-pair telephone cable laid alongside and a pair of these wires was used to make up the loop. Fig. 5 shows the connections of the faulty cable to the instruments :—

Route length
of cable = 10,741 yds. 0.1 sq. in.
231 ,, 0.15 ,,
10,972 ,,

Length calculated in terms of 0.1 sq. in. = 10,900 yds. approx.

Resistance value of S = 1,000 ohms.
,, ,, R = 784 ,,
Resistance of telephone wire connected to bridge arm = 205 ,,

Distance of fault

$$= \frac{10,900 \times 784}{1,000 + 784 + 205} = 4,297 \text{ yds.}$$

Actual distance of fault was 4,304 yds., or 7 yds. short, giving an accuracy of within .16%.

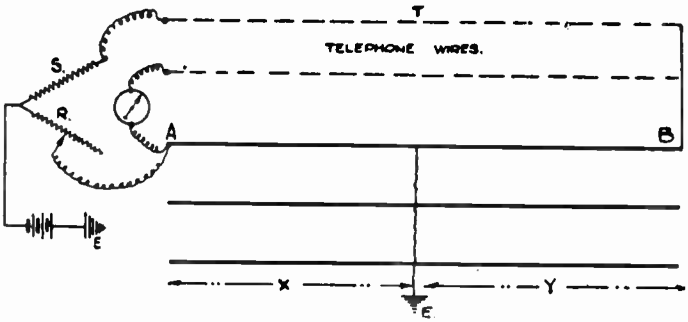

Fig. 4.—CONNECTIONS FOR USING AN INDEPENDENT OR ADJACENT CABLE.

Checking of Tests.

A check test should be made where possible, either by taking a test from the opposite end or by reversing the connections on the "bridge" which will give the fault position the opposite way round the loop. If the two fault positions obtained agree, the test may be taken as accurate. Should, however, there be any large difference, either bad connections or some defect in the cable forming the loop may be looked for. If by chance there be two faults, the test will indicate a position somewhere between them, in which case the cable should be cut at this point and a fresh location made on each section.

HIGH RESISTANCE FAULTS.

The extensive use of super-tension cable has brought in its train a number of subsidiary problems, one of these being the location of high resistance faults, the

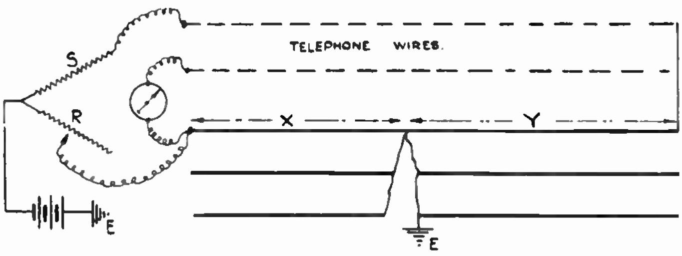

Fig. 5.—DIAGRAM SHOWING CONNECTIONS OF THE FAULTY CABLE TO THE INSTRUMENTS.

features of which may be enumerated as follows :—

1. Quick acting protective devices.
2. Thickness of dielectric.
3. Semi-fluid compound in joints.

To make the location of faults possible in these circumstances it has often been necessary to connect the faulty cable to the System, or to a separate generator, in order to lessen the resistance path at the fault ; such arrangements occasion appreciable delay, apart from being injurious to generating plant. To overcome some of these difficulties, the cable manufacturers, in co-operation, have developed special fault-locating apparatus for producing a suitable source of high-voltage D.C. which can be used for breaking down high resistances and locating faults simultaneously.

The kVA. required to test super-tension cables with A.C. current is so considerable as to be impracticable owing to the testing-transformers being so unwieldy and heavy.

For instance, a 20 kV. cable, 6,000 yards long required nearly 11 tons of apparatus taken some considerable distance to the site of a test in order to break a high resistance fault down with A.C. current, whereas the same object could have been achieved with D.C. apparatus in portable form, the weight of which would not have exceeded 6½ cwts.

DESCRIPTION OF HIGH PRESSURE TESTING APPARATUS.

Before describing the method of this test, a word or two about the type of apparatus which is being successfully used would be helpful. It consists of two main units Nos. 1 and 2, each of which is enclosed in a wooden casing.

Unit No. 1.

This contains the main E.H.P. transformer designed for a primary supply of 200—240 volts and a maximum secondary voltage of 60 kV.

A smaller insulated current transformer is mounted in the same sheet steel tank for supplying the heating to the filament of a thermionic rectifying value. The primary is arranged to work from a 230-volt supply, and the secondary is arranged to have an output of 8 amperes at 8 volts. The secondary winding is insulated from the primary for a working pressure of 60 kV. D.C. Provision is made for mounting an E.H.P. valve on the top of the bushing from which the leads from the current transformer are brought. In addition a filament voltmeter is mounted on the top of the bushing. A sphere gap voltmeter with 62.5 mm. spheres is provided for measuring the peak voltage on the cable, and also acts as a discharge path in the event of surges being set up on the line. The dimensions of the case containing this apparatus is 20 inches by 17 inches by 16 inches high and the approximate weight is 220 lbs.

Unit No. 2.

This is the control unit and is fitted with the following :—

Auto-transformer control switch.
Ironclad main switch and fuses.
Filament switch and fuses.
Two filament rheostats.
Primary voltmeter five-inch dial.
Milliammeter four-inch dial with ranges 0-5, 0-50 milliamperes.

The panel is mounted in an oak case in which is fitted a 3 kVA. auto-transformer having 20 tappings 0 to 230 volts. Flexible connections are provided for the purpose of making connection between the control unit and the transformer unit. The approximate dimensions of this case is 20 inches by 24 inches by 16 inches deep, and the approximate weight is 80 lbs.

The cases are provided with sliding lids

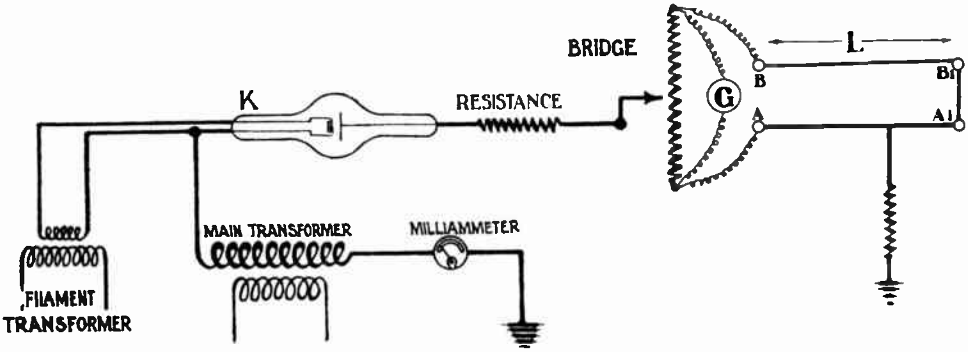

Fig. 6.—CONNECTIONS FOR HIGH PRESSURE TESTING APPARATUS.

into which protective resistances and sundry fittings are packed.

Electrostatic Voltmeter.

An electrostatic voltmeter of the Abram-Villard type is recommended for measurement of the test pressures in addition to the sphere gap.

Portable Engine Driven Alternator Set.

In order that a suitable L.P. supply be always available, a special portable alternator set on trailer is provided, comprising 2 cylinder, vertical, 4-cycle, stationary water-cooled petrol engine, developing 5—6 B.H.P. at 1,500 r.p.m. direct coupled to which is a two-bearing single-phase alternator, developing 3 kVA., 0.8 power factor, 230 volts, with direct-coupled exciter.

High Pressure D.C. Localising Bridge.

In making tests with this apparatus, it is necessary to have a special " bridge " insulated for working at high pressures. Several " bridges " have been designed for this purpose and the one used in connection with the above apparatus consists of a rotating slide-wire drum localiser mounted on porcelain insulators. The drum shaft is coupled through a universal coupling to a 3-foot insulating rod, the other end of which is terminated by a brass shaft to which the operating wheel is attached. A galvanometer with a vertical scale is placed on top of the localiser so that the scale faces the operator. Near the operating wheel, attached to the main framework, is a reading telescope for magnifying the scale of the galvanometer. The " bridge " works on the " Murray " loop principle. Connection is made to the sliding contact of the " bridge " with a lead from the high-pressure apparatus.

Procedure of Testing.

The principle is the same as that applied in the low voltage slide-wire bridge tests previously described. It is merely that the high-pressure D.C. generator set displaces the battery. When a location test is to be applied, the connections are first made according to Fig. 6.

The primary current of the filament transformer is switched on and regulated by means of rheostats so as to pass the correct current for the efficient working of the valve. It is essential that the correct filament voltage should be adhered to, and for this purpose a voltmeter is provided with the equipment connected across the leads to the valve filament.

The voltage control is set for the minimum pressure on the cable before closing the main circuit. By means of a special control, the test pressure can be raised gradually to any required value within the capacity of the set. A milliammeter is provided to indicate the current that leaks through the fault to " earth " when sufficient pressure has been applied to the faulty conductor to permit of the passing of about 15—20 m.a. The operating wheel of the bridge is turned until the galvo. needle settles at zero. The ratio $X/{}_2L$ as a percentage is given directly on the localiser scale (X being the distance to the fault and " L " the total route length of the cable).

Breaking Down High Resistance.

In breaking down the high resistance of an incipient fault, such as intermittent flashovers in a joint, a great deal of care and patience is required. Cases have been known where the maximum testing pressure has been maintained for 24 hours with occasional discharges through the fault, before sufficient current could be held long enough for the location test to be carried out.

L = Route length of cable.
AA = Faulty conductor.
BB = Good conductor.
K = Kenotron rectifying valve.
Milliammeter to read fault current in loop.

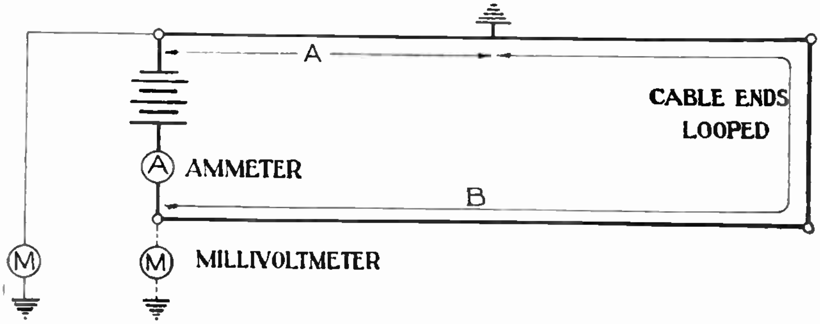

Fig. 7.—" FALL OF POTENTIAL " TEST.

Example of Test.

The following are actual particulars and figures taken on a cable breakdown where the location test was made with the apparatus :—

A 0.05 square-inch 20 kV. cable tripped out of circuit on fault and the insulation resistance test revealed the conditions as follows :—

Red phase 2 megohms to " earth."
White phase 4 megohms to " earth."
Blue phase 10 megohms to " earth."

It was obvious from the test that the cable had broken down and therefore was not sound enough to be switched in again. The high pressure apparatus was applied as in Fig. 6 to the red phase conductor, which, at a pressure of 10 kV., passed a current of 15 m.a. through the fault. The galvo. was then adjusted to zero, when a reading of 30.11 divisions was obtained on the " bridge " scale.

Route length of
0.05 sq. in. cable = 3,964 yds.
Test leads, 27 yds. 0.1 sq. in. = 27 ,,

From this we obtain the position of the fault as follows :—

Loop length (3,964 yds. × 2) = 7,928 yds.
Test leads as 0.05 sq. in.

$$\frac{27 \text{ yds.} \times 0.05 \text{ sq. in.}}{0.1 \text{ sq. in.}} = 13.5 \text{ ,,}$$

Total length as 0.05 sq. in. = 7,941.5 ,,

Distance of fault

$$= \frac{7{,}941.5 \times 30.11}{100} = 2{,}391 \text{ yds.}$$

Actual distance = 2,361 yds.

It should be mentioned that immediately the pressure was taken off, the insulation resistance of the faulty conductor was still in the order of 2 megohms.

The distance of the fault worked out near a joint which on being examined was found with a small hole in the lead sleeve. The joint was of an expansion type and had broken down due to ground movement on a main road. The actual fault had developed in the cable outside the sleeve. The lead was found broken near the wipe, through which water had entered and found its way into the joint.

" Fall of Potential " Method.

This is another method that can be used for locating faults similar in nature to those located by loop tests, with this advantage, that it can be applied whether a sound conductor is available or not. It is simple and accurate under certain conditions, and where the fault resistance is sufficiently low to allow of a steady current to be maintained through the fault. The " drop " is noted at both ends of the cable by means of a millivoltmeter as the current from a secondary battery is passed to "earth" through the fault, the current being maintained steady through a reliable ammeter. The formula for obtaining the distance of the fault would be :—

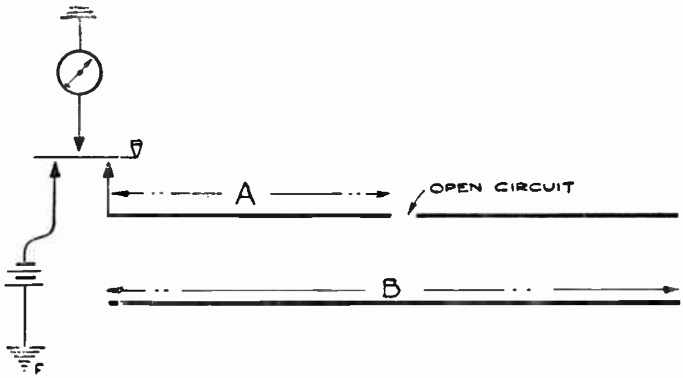

Fig. 8.—Simple Comparative Deflection Test for Locating an Open Circuit.

Formula.

L = length of faulty cable.

D_1 denotes drop from first testing position.

D_2 denotes drop from second testing position.

Distance of fault from first testing position

$$= \frac{L}{D_1 + D_2} \times D_1$$

Using a Sound Conductor.

A modification of this test is to use a sound conductor of the same section area as a test lead by passing a current round the loop as shown in Fig. 7, the advantage being that no current passes through the fault. When it is necessary to use conductors of different sectional area for the return conductor, the equivalent lengths, as previously explained, must be calculated to put them in terms of the faulty cable.

Formula.

L denotes entire loop of sound and faulty conductors.

A denotes reading on faulty cable.

B denotes reading on sound cable.

Distance of fault

$$= \frac{L}{A + B} \times A.$$

This method is not to be recommended for faults that have any resistance in them, and experience shows this to be the case with most super-tension cable breakdowns. With the "Murray" loop test it is possible to locate very high resistance faults by increasing the battery power. With a primary testing battery of about 300 volts, a fault of 0.5 megohm has been located to a drum length on a 20 kV. cable 11 miles long. It is much to be preferred, however, with high resistance faults, to deal with them by the special apparatus already described.

In all these tests, particular care should be taken to see that the instrument connections are clean, carefully made, and perfectly dry, as damp test leads will lower the resistance of all circuits and probably render the tests inaccurate.

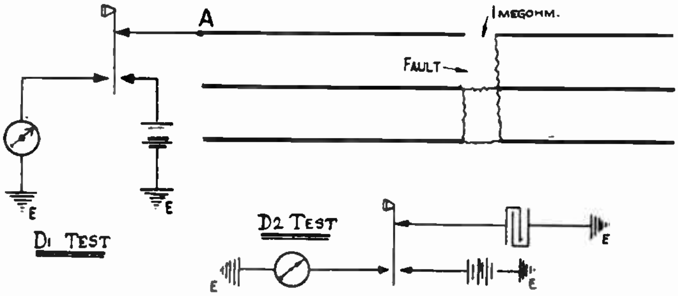

Fig. 9.—Testing a Fault Caused by "Short Circuit" Between Phases.

OPEN CIRCUIT FAULTS

Capacity Tests.

This method of location is applied to cables that become open-circuited when the insulation resistance of the fractured conductor or conductors is sound. The principle of the test is the comparison of the electrostatic capacity of the severed conductor against a sound one of the same cable or standard condenser. The accuracy of the test depends entirely upon the dielectric of the conductors to each other and the sheath, which should be alike in quality and thickness. For this reason, wherever possible, the size, manufacture, etc., of all cables should be kept uniform.

Locating a Simple Open Circuit.

Fig. 8 shows the connection of a simple comparative deflection test for locating a simple open-circuit on a conductor where all conductors are found to be sound between the conductors and lead sheath. The instruments required are:—

High insulation 2-way key.
Ballistic galvanometer.
100-volt battery.

A charge is given to the severed conductor for a given period by depressing the key, which on release gives a discharge through the galvo., a careful note being made of the deflections. It is always advisable to have the galvo. shunted whilst trial readings are taken in order to prevent damage to the instrument, as the position and capacity discharge to the fault is unknown. Without removing the instruments, repeat the test on the continuous conductor, using the same battery power and time-charge.

Formula.

L = total length of cable.
A = deflections on faulty conductor.
B = deflections on sound conductor.

$$\text{Distance of break} = \text{Length} \times \frac{A}{B}$$

When the fault has been caused by a "short-circuit" between phases, this may give rise to complications with all conductors completely severed and only one end left for testing purposes. The procedure in this case would be to measure the capacity of the broken conductor up to the break and compare it with the capacity per unit length of the cable.

Severed Conductor.

A test is taken at the insulated end of the severed conductor as already described, then without moving the instruments, using the same battery power, charge and discharge a standard condenser of known capacity in like manner. Then if—

D_1 = deflections on severed conductor,
D_2 = deflections on standard condenser,
$K1$ = capacity of standard condenser,
$K2$ = capacity to be found.

Formula.

$$K2 = \frac{D_1 \times K1}{D_2}$$

Having thus obtained the capacity of the conductor up to the break, by reference to the cable standard per unit length of the class of cable under test, the fault position will be:—

$$\text{Distance of fault} = \frac{\text{Unit length} \times K2}{K1}$$

Example of Test.

The following is an example of the condition and test figures of an actual fault:—

A 20 kV. 0.05 square inch cable, 6,380 yards long, broke down with all the conductors severed, with only the insulation resistance good on one severed conductor from one end, the remainder being "earthed." (See Fig 9.)

Test.

D_1 discharge deflections on severed conductor .. 300
D_2 discharge deflections on standard condenser .. 65
$K1$ standard condenser 0.1 microfarad.

$$\frac{D_1}{D_2} \times K1 = \frac{300}{65} \times 0.1 = 0.46 \text{ microfarad.}$$

0.46 microfarad equals capacity to the fault.

0.18 microfarad maker's capacity per 1,000 yards.

Then $\frac{0.46}{0.18} = 2{,}555$ yards.

Whilst this form of test is very simple, care must be taken in obtaining the galvo. readings. The accuracy depends upon the insulation resistance across the path of fracture and also against the other conductor and the sheath.

(Photographs and diagrams are by kind permission of the Newcastle Electric Supply Co., Ltd., and the British Insulated Cables, Ltd.)

SOME LABORATORY AND TEST ROOM APPARATUS

By A. C. JOLLEY, A.M.I.E.E., F.Inst. P.

IT is convenient to divide electrical instruments into two classes :—

(*a*) Industrial and indicating instruments.

(*b*) Precision and standardising instruments.

Typical instruments of the first class have been already described in previous articles. The second group is a very wide one and includes apparatus for the absolute determination of electrical units and also for refined research, as well as the apparatus employed for the precise determination and comparison of electrical quantities, such as electrical pressure, current, resistance, capacity inductance, etc.

This article will deal with some typical examples of apparatus which is usually found in a well-equipped laboratory or test room.

THE UNIT OF ELECTRICAL PRESSURE —THE INTERNATIONAL VOLT.

The practical unit of electrical pressure is the international volt, and in order to realise and maintain this unit we must refer to some form of standard which takes the form of a primary cell set up in accordance with a carefully drawn up specification.

The Clark Standard Cell.

The earliest form of standard cell was described by Latimer Clark in 1874. Essentially this cell consisted of a pure zinc electrode in a neutral saturated solution of zinc sulphate, the positive pole being pure mercury covered with a paste of zinc sulphate and mercurous sulphate, the latter acting as a depolariser.

The Weston Cell.

Dr. Weston in 1892 suggested a standard cell similar to the Clark cell, in which the zinc amalgam was replaced by a cadmium amalgam and the zinc sulphate solution by a solution of cadmium sulphate.

This type of cell is now almost universally employed as a standard. When properly set up the cadmium cell forms a most reliable standard. The E.M.F. at 20° C. in terms of the international ampere and ohm is given as 1.01830 volts and at any temperature t° C. the E.M.F. is expressed by the equation

$$E_t = E_{20} - 0.0000406\ (t - 20) - 0.00000095\ [t - 20]^2$$

The form which the modern cell takes is shown in Fig. 1, and usually the cells are mounted in pairs, one of which is reserved to act as a comparison cell against which the other or working standard can be checked from time to time.

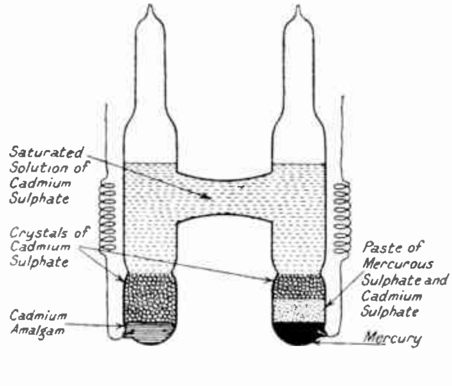

Fig. 1.—THE WESTON NORMAL CADMIUM STANDARD CELL.

Accurate Measurement of Voltage by Comparison with the Standard Cell.

The measurement of potential difference by comparison with the standard cell* is usually made by means of some form of potentiometer. The principle consists of establishing by means of a battery of constant E.M.F. a known volt fall over a series

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* Standard cells should never have appreciable current drawn from them and should therefore always be employed only on circuits of very high resistance, although it has been shown that if given a sufficiently long rest on open circuit after an accidental short circuit the cell will completely recover its E.M.F.

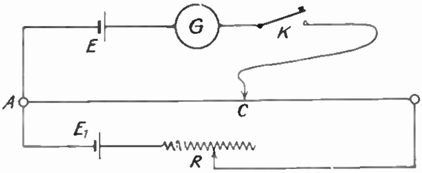

Fig. 2.—Connections for Measurement of Potential Difference by Comparison with the Standard Cell.

of resistance coils which in some cases is supplemented by a slide wire.

The P.D. to be compared is then applied to the arrangement and two points are found between which the volt fall is equal to the unknown P.D., the equality being indicated by the absence of current in a sensitive galvanometer joined in series with the unknown P.D. Thus in the diagram Fig. 2 A B is a long uniform slide wire along which a steady current is maintained by the battery E_1, and since the wire is uniform there will be a uniform fall of potential along its length, say, from the positive end A to the negative end B and we can mount a scale of uniform divisions beside it.

Let us suppose we give this scale 200 divisions. We must now standardise the volt fall and to do this we connect the positive terminal of a standard cell E to the end A of the wire and the negative terminal through a sensitive galvanometer G to a sliding contact C on the wire. Now suppose we desire a volt fall of 0.01 volt per division on the wire and the E.M.F. of the standard cell is 1.018 volts, we set the contact C to 101.8 divisions on the scale and on pressing the key K the galvanometer will be deflected.

The rheostat R in series with the battery E_1 is now adjusted until there is no deflection of the galvanometer on operating the key K and we then know that the current flowing in the wire produces a volt fall of 0.01 for a length of it corresponding to one division on the scale.

We may then replace the standard cell by the unknown P.D. and without altering anything else in the circuits we find a new point of balance on the wire; let us suppose that this occurs at 143.5 divisions on the scale, then we know that the unknown P.D. is 143.5 × 0.01 = 1.435 volts.

The Crompton Potentiometer.

One of the earliest improvements on this simple form of apparatus was made by Colonel Crompton and Professor Fleming, who substituted for the long wire a series of 14 coils and a comparatively short slide wire as shown in Fig. 3. Each coil has a resistance exactly equal to that of the slide wire so that the whole becomes equivalent to 15 slide wires, but is obviously much more compact. We can now have a volt fall of, say, 0.1 volt per slide wire and if the straight wire has a scale of 100 divisions the volt fall along it will be 0.001 volt per division.

The galvanometer used with this apparatus is usually a reflecting moving coil instrument of fairly high resistance and designed to have good zero keeping qualities.

The Vernier Potentiometer.

The Crompton form of potentiometer is usually classed as a low resistance instrument since its total resistance is determined by the resistance of the slide wire. There are, however, many modifications of the potentiometer which aim at obtaining a higher internal resistance and some eliminate the slide wire entirely by employing a vernier arrangement of resistance coils in which each succeeding dial is shunted across two coils of the preceding dial by means of a double brush switch.

An arrangement of three dials is shown in Fig. 4, and it will be seen that with this arrangement the resistance of the potentiometer may be made as high as

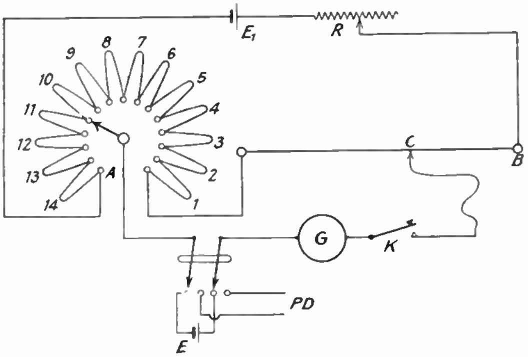

Fig. 3.—Diagram of Connections for Crompton Potentiometer.

we desire. For instance, the first dial may be a series of 16 coils each of 1,000 ohms, the second dial will then contain 11 coils of 200 ohms each, and if the third dial is the last, as in our diagram, it will have 10 coils of 40 ohms each and a single brush travelling on it. Obviously, we may have any convenient number of dials in such an instrument and each dial represents tenths of the preceding unit.

The Tinsley Potentiometer.

Another arrangement is shown diagrammatically in Fig. 5. The first dial has a volt fall of 0.1 volt per coil and the slide wire is connected in series with it. The second dial shunts two coils of the first by means of the double travelling brush switch. The unknown P.D. in series with the galvanometer is connected between the travelling contact on the slide wire and the single brush which makes contact with coils of the second dial. Thus we read tenths of a volt on the first dial, hundredths of a volt on the second dial and the remaining fractions are indicated by the balance position of the slider on the scale of the slide wire.

The "Volt-box."

In general the range of a potentiometer is not much greater than 1.5 volts, since the potentiometer current is usually supplied by a single secondary cell and therefore the total applied E.M.F. is approximately 2 volts. To extend the range to higher values it becomes necessary to employ what is known as a "volt-box," which is really a fixed value potential divider.

Essentially it consists of a high resistance across which the voltage to be measured is applied, a tapping is taken off this resistance at such a value from one end of it that the volt fall, when the nominal voltage is across the whole resistance, is within the range of the potentiometer.

Accurate Measurement of Supply Voltages (D.C.).

Thus suppose we desire to measure a pressure of 100 volts, we might make the main resistance 100,000 ohms; there would then be a volt fall of 1 volt per 1,000 ohms, and it, therefore, a tapping is brought out from the first 1,000-ohm coil as in Fig. 6 and taken to the potentiometer there will always be between these leads one-hundredth of the voltage applied across the main resistance. Obviously, we may by means of suitable tappings along it make the main resistance serve for a wide range of applied voltages.

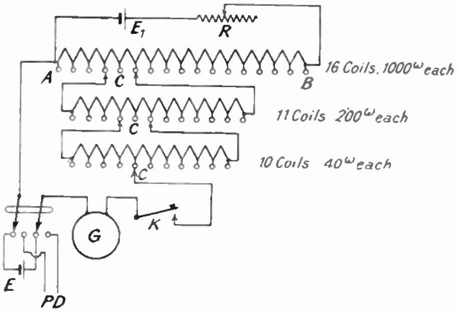

Fig. 4.—ARRANGEMENT FOR THREE DIALS.

Increasing the Sensitivity of a Potentiometer.

When the voltage to be measured is small the accuracy with which the potentiometer may be read becomes very limited. To overcome this difficulty a transposition arrangement is often fitted which is in the form of a two-way plug switch as shown in Fig. 7. With the plug in A the potentiometer reads in the ordinary way, but if the plug is shifted to position B a resistance equal to one-ninth of the potentiometer resistance is shunted across the instrument and at the same time a resistance nine times that of the potentiometer is put in series. In this way the current drawn from the battery remains unchanged, but the current flowing in the potentiometer coils is reduced to one-tenth, so that the volt fall over the potentiometer coils is reduced to one-tenth, and therefore the maximum reading of the instrument is also one-tenth of its unshunted value.

With a good potentiometer, a volt-box and a set of standard resistances or shunts it becomes possible to measure voltage, current, power, resistance and, in fact, practically all direct current quantities with considerable accuracy, in terms of the E.M.F. of a standard cell. The chief defect of the potentiometer system of measurement is the time required to make the individual settings, particularly if the conditions in the circuits under test are unsteady.

Increasing the Convenience of the Potentiometer.

In part, this difficulty is due to our having frequently to refer back to the standard cell to verify the potentiometer current. To facilitate this being rapidly done many potentiometers are provided with a supplementary standard cell dial in series with the potentiometer coils and graduated to correspond with the E.M.F. of the cell at various temperatures and so arranged that the galvanometer and the standard cell may be switched across its resistance without altering the last potentiometer setting and since it is in series with the potentiometer if the galvanometer shows a deflection the current through the instrument is adjusted to balance, after which the galvanometer is transferred to its original position and the readings continued.

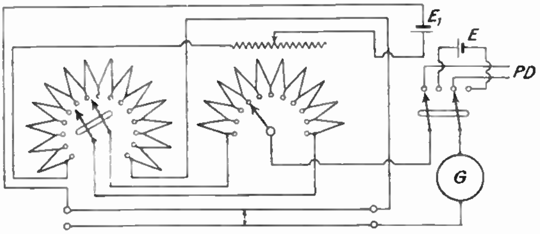

Fig. 5.—ARRANGEMENT FOR TINSLEY POTENTIOMETER.

The Brooks Deflection Potentiometer.

Still greater speed of setting is obtained in the deflection potentiometer of Brooks. In this approximate settings are made on the dials of the instrument and the residuals to be added or subtracted from the dial readings are read on the scale of a moving coil instrument. In order that these deflections shall truly represent the residual fractions of the E.M.F. a special arrangement of the resistances of the potentiometer has to be adopted so that the resistance in the galvanometer circuit remains constant for all settings of the dials and the rheostat in series with the battery supplying the instrument.

ACCURATE A.C. MEASUREMENTS.

When we are dealing with alternating quantities we cannot concern ourselves only with magnitude, but we must also take into account the phase of the E.M.F. which is being measured.

There are two alternatives open to us. First, we may provide some means to bring the potentiometer current into phase with the E.M.F. being measured, or, secondly, we may measure the rectangular components of the P.D. under investigation. Both these alternatives have been developed into practical instruments.

The Drysdale Polar Potentiometer.

The polar potentiometer of Dr. C. V. Drysdale employs the first. It consists of an ordinary D.C. potentiometer in whose main circuit is included a dynamometer millammeter, which serves to indicate the potentiometer current, whether D.C. or A.C. A double pole change-over switch switches either a secondary cell or the secondary of the phase shifting transformer.

This latter consists of a laminated slotted stator wound on a two-phase scheme like an ordinary induction motor stator; within this stator is a laminated rotor on which a secondary coil is wound, and this rotor may be turned into any position relatively to the stator winding by means of a worm gear.

How the Stator is Excited.

The stator is excited from a single-phase supply on the split phase principle; that is to say, one of its phase windings is supplied directly, and the second winding, which is in space quadrature, is supplied through a suitable resistance and condenser. The windings are identical, and when the phase is properly split a perfectly circular and uniform rotating field is produced, which links with the secondary coil and generates an E.M.F. in it whose R.M.S. value is practically equal to the E.M.F. of the secondary cell.

Obviously, the phase of this secondary E.M.F. will depend only on the position of the axis of the secondary in relation to the primary winding. Thus if this axis corresponds with the axis of the directly excited phase of the primary, the secondary E.M.F. will be in phase with the supply. If the rotor is turned so that the axis coincides with the other phase of the stator, which is excited through the condenser, its E.M.F. will be in quadrature and for all intermediate positions the phase of the secondary induced E.M.F. will be given by the angular position of the rotor.

A terminal board above the potentiometer allows, in connection with the two-pole selector switch of several circuits being switched in successively.

Galvanometers for A.C. Working.

Obviously, the ordinary moving coil instrument cannot be used since it is an average instrument and therefore will give no indication at all on A.C. A dynamometer or sensitive electrometer could be used, but unless both were separately excited they will have a square law, and are consequently very insensitive near their zero, which is just where we require the greatest sensitivity to indicate balance. If the frequency is within the audible range, we can use a telephone as a detector, but a better alternative at moderate frequencies is to employ a vibration galvanometer.

The invention of this type of A.C. detector has marked a very great advance in alternating current measurement.

The vibration galvanometer is similar to a sensitive moving coil or moving iron D.C. instrument, the essential difference being that instead of giving the moving system a comparatively slow periodic time we tune it until its natural period is exactly that of the supply. The tuning in the case of the moving magnet instrument is done either by altering the length and tension of the suspension string to which the magnets are attached or by altering the strength of a steady magnetic control field. With moving coil instruments the tuning is always done by altering the length and tension of the metallic suspension of the coil.

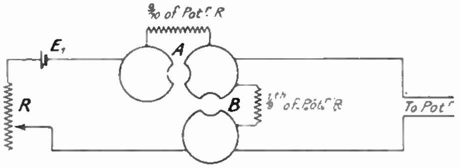

Fig. 7.—ARRANGEMENT FOR INCREASING SENSITIVITY OF POTENTIOMETER.

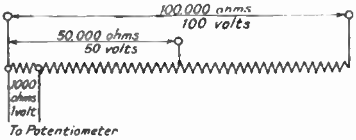

Fig. 6.—CONNECTIONS FOR ACCURATE MEASUREMENT OF SUPPLY VOLTAGES (D.C.).

Such galvanometers are very satisfactory for all measurements where balance or null methods are employed. A typical form of vibration galvanometer is shown in Fig. 8.

Using the Polar Potentiometer for Measuring A.C. Voltage, Capacity and Inductance.

To make a measurement with the polar potentiometer, therefore, we first connect the instrument to an accumulator and, employing an ordinary moving coil galvanometer and standard cell, the instrument is standardised in the manner already described, and when the standard cell is balanced, the reading of the dynamometer is carefully observed.

This standardisation once made need not be repeated, except at long intervals in order to check the constancy of the potentiometer construction.

The connections of the instrument are now changed by turning the change-over switch so that the instrument is supplied from the secondary of the phase shifting transformer and the potentiometer current is adjusted by means of the rheostat until the dynamometer indicates that the same current is passing as when the instrument was standardised with D.C., and this current is maintained throughout all observations.

The galvanometer is replaced by a vibration galvanometer, which is tuned to the frequency of the supply.

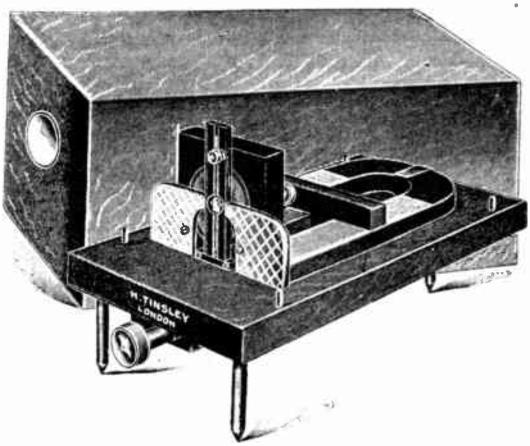

Fig. 8.—Typical Form of Vibration Galvanometer.

In making any measurement the circuit under investigation must always include a low non-inductive resistance standard and the P.D. over this is first balanced by setting the potentiometer dials and slider until minimum deflection is obtained; the final balance is then obtained by turning the rotor of the phase shifter. The spindle of this transformer carries a system of pointers at right angles to one another, one of which is marked "index," and these pointers move over a scale graduated in degrees over two right angles on one side and has a scale of cosines in the remaining two quadrants.

Now, since we know that with a truly non-inductive resistance the P.D. across it must be in phase with the current it carries, we can set the index pointer, which is adjustable on the rotor shaft, over the zero of the degree scale.

Measuring the Voltage and Phase Difference.

If now, by means of the selector switch, we connect in the unknown P.D. which we desire to measure we again balance by dial setting, which gives the magnitude, and by turning the rotor of the phase shifting transformer, which, when balance is obtained, gives the phase angle between the current and the voltage being measured.

Impedance, Capacity and Self Induction.

If the first reading was V_1 on the non-inductive resistance whose value is R ohms, and V_2 is the second reading on the apparatus or load under investigation, then

$$I = \frac{V_1}{R}$$

and Z the impedance of the load will be

$$\frac{V_2}{I}$$

The cosine of the angle can be read off on the cosine scale under the pointer marked "cosine" and the sine similarly under the pointers marked "sine" then the reactance of the load is $Z \sin \theta$ and the power taken by the load is $V_2 I \cos \theta$, the effective resistance is $Z \cos \theta$ and if the frequency is known the self-induction or capacity of the load is determined.

A Multi-purpose Instrument.

It is at once evident that such an equipment is probably one of the most widely useful measuring devices which has ever been invented since it allows of nearly every measurement within the range of D.C. and A.C. measurements being made with reasonable accuracy, and practically without restriction of magnitude, providing suitable shunts and volt boxes are available. The accuracy is limited to that to which the potentiometer dynamometer can be made to reproduce its readings, which is high. It should, however, be remembered that *any measurements made with the aid of a vibration galvanometer or any tuned detector must be carried out exactly at the frequency to which the galvanometer is tuned*, since even a small difference on either side between the frequency of the supply and the natural frequency of the instrument will result in a serious loss of sensitivity. At its best, the polar A.C. potentiometer is essentially a low frequency arrangement and is very difficult to apply to frequencies above 1,000 cycles. This restriction does not, however, apply to the second alternative, that of measuring the rectangular co-ordinates of the voltage under investigation. In many instances it is very convenient to do this, but generally co-ordinate potentiometers are less simple to manipulate.

The Gall Co-ordinate Potentiometer.

The co-ordinate potentiometer of

Mr. D. Gall was the first commercial instrument of this type to be put on the market.

Essentially it consists of two potentiometers, one of which is fed by a current in phase with the supply and the other through a phase-splitting device with a current in quadrature. The exactness of the quadrature relation, which is, of course, of first importance, is ascertained by balancing the secondary P.D. of a fixed value mutual inductance on the inphase potentiometer when the primary of the mutual carries the quadrature potentiometer current. This secondary P.D. is arranged to be equal in volts to the primary frequency divided by 100.

The instrument is standardised as in the polar instrument by balancing the standard cell on the inphase potentiometer, a delicate torsion dynamometer instrument being used to indicate the potentiometer current. The slides of the two potentiometers are interconnected through the vibration galvanometer and the unknown P.D. to be measured, so that balance is obtained by adjusting both potentiometers until the galvanometer is balanced at zero.

The inphase component is then the reading of the inphase potentiometer, while the quadrature component is given on the other.

The Larsen-Campbell Potentiometer.

Another arrangement for a co-ordinate potentiometer was devised by Larsen and modified by A. Campbell. In this case the potentiometer consists of an arrangement of resistances in series with the primary of a variable mutual inductance, the combination being put directly across the supply pressure.

An ingenious thermal indicating device, which can be calibrated by means of a direct current, is put in series with the potentiometer to indicate when the correct current is passing.

The pressure to be measured is balanced by travelling contacts on the resistance in series with the secondary of the mutual inductance. The inphase component is therefore balanced on the resistance slides, while the quadrature component is balanced by varying the mutual inductance. This balance is made independent of frequency by Mr. Campbell's ingenious application of the universal shunt principle to the resistances.

The advantage of the co-ordinate potentiometer, and particularly the latter form, is that it may be used without modification on audio frequency circuits.

THE UNITS OF RESISTANCE—THE INTERNATIONAL OHM.

Next in importance to potential measurement are resistance determinations.

The Mercury Standard.

The practical unit of resistance is the international ohm, represented by the resistance of a column of pure mercury 106.3 cm. long and weighing 14.4521 grammes at 0° C.

Copies of the Standard for Laboratories.

Such a standard, however, is not generally suitable for ordinary laboratory work, so that it is replaced by copies in the form of wire coils wound in an alloy of permanent properties and low temperature coefficient.

Why Manganin is Used and Why it is Varnished.

Of recent years all good resistances are wound in manganin, an alloy of copper, manganese and nickel, and containing also a small percentage of iron, which has considerable influence on its temperature coefficient. Manganin has been found most satisfactory for the construction of permanent resistance standards, particularly when protected by a suitable varnish coating from the selective oxidation of the manganese, which takes place when the material is exposed to the air and which leads to a high positive temperature coefficient.

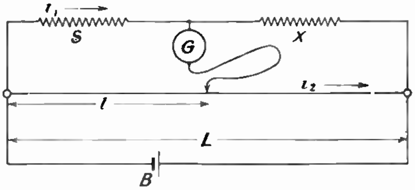

Fig. 9.—Simplest Form of Wheatstone Bridge.

How Standard Resistances are Wound.

All resistances are wound bifilarly; that is, the insulated wire is bent back upon itself before winding so that adjacent turns carry current in opposite directions and are therefore noninductive. For D.C. working this is usually sufficient.

Special Types for A.C. Work.

With alternating currents, at audio and higher frequencies, the residual inductance and capacity of the coils becomes of considerable importance and special methods of winding and mounting the coils have to be adopted so that these effects are reduced to a minimum, while careful attention must be given to screening the coils in order to eliminate variable earth capacities.

The Wheatstone Bridge and Its Use.

Resistance determinations always involve comparison between the apparatus under investigation and a set of coils whose values are known, and such comparisons are most frequently made by some form of Wheatstone bridge.

In its simplest form this can consist of a uniform wire across which a set of known resistances and the unknown resistance in series are connected as in Fig. 9. Current is sent through the parallel combination by the battery B and the galvanometer is joined between the junction of the resistances and the slider on the wire.

Then a current i_1 will flow through S and X, while another current i_2 will flow in the slide wire. The volt fall over S is equal to $i_1 S$, and by moving the contact on the slide wire a point is found where no current passes through the galvanometer; when this is the case it is obvious that there can be no difference of potential between the two points to which the galvanometer is connected.

Therefore if the balance point is a distance l cm. from the end, we know that the volt fall over this length must be $i_2 R l$ where R is the resistance of unit length of the wire. We therefore have $i_1 S = i_2 R l$.

Then obviously we must have $i_1 X = i_2 R (L - l)$ where L is the total length of the wire. Dividing these equations one by the other we get

$$\frac{X}{S} = \frac{L - l}{l} \text{ or } X = S\frac{L - l}{l}$$

The quantities $(L - l)$ and l form the ratios of the bridge and the arrangement becomes more compact and less likely to damage if we replace the slide wire by two sets of fixed ratio coils and make S an adjustable resistance, which is equivalent to fixing the sliding contact at some point on the wire so that the volt fall over it can be matched by varying S. We have then arrived at the ordinary form of Wheatstone bridge.

Each ratio arm usually consists of four coils having values of 1, 10, 100, 1,000 ohms. These are arranged at the back with the adjustable resistance forming the third arm in front of them. The battery is connected to the middle point, where the ratios join, and to the junction between the unknown resistance and the adjustable bridge arm, while the galvanometer is joined directly across the ratios.

This is the usual arrangement, but, obviously, we may interchange the position of the galvanometer and battery without affecting the principle and under certain circumstances this may be advisable.

Possibilities of the Wheatstone Bridge.

The range of the ordinary Wheatstone bridge can be made very wide. For if we call the resistance of the ratio on one side N and on the other side M, the relation

$$X = S\frac{N}{M}$$

holds for all values of N and M. We can therefore use level ratios or ratio up for high resistances or down for low values.

In practice, however, the bridge arrangement loses sensitiveness, and there is a danger of over-heating some of the coils if the use of unlevel ratios is carried too far.

The practical range is from about 0.1 ohm to 100,000 ohms, and although measurements can be carried beyond this, other arrangements are then to be preferred.

The Kelvin Double Bridge.

For low resistances a modification of the

Wheatstone bridge known as the Kelvin double bridge gives results of great accuracy. Diagrammatically the arrangement is shown in Fig. 10, and it will be seen that this is an ordinary Wheatstone bridge except that the two inner ratio coils m and n have been introduced to shunt the connection between X and S and the galvanometer is then taken to their common centre. Then, obviously, if m and n are equal high resistances the galvanometer is connected to what is equivalent to the electrical centre of the connecting bar α.

If α is the resistance of the interconnector the condition of balance is

$$X = \frac{N}{M} S - \alpha n \frac{\frac{n}{m} - \frac{N}{M}}{m + n + \alpha}$$

And, obviously, if we make

$$\frac{n}{m} = \frac{N}{M}$$

then

$$X = S \frac{N}{M}$$

as in the ordinary bridge.

Many bridges for the most accurate intercomparison of standards of resistance are built up on this principle. For commercial and industrial measurements the bridge is made up with the ratios n and N of fixed values, say, 1, 10, 100 and 1,000, and are put into circuit by the ordinary plug arrangement. The other ratios m and M are arranged on the decade system, the brush contacts on each being mechanically coupled so that they are varied together.

Wheatstone Bridge for A.C. Measurements.

Apart from the measurement of resistance, the Wheatstone bridge arrangement has been very extensively employed with alternating currents for the determination of capacity inductance, etc., for the bridge relations hold for the impedances of the arms just as it does for the resistances. If, therefore, we replace the battery by a suitable source of alternating current and the galvanometer by a vibration galvanometer or for the higher audio frequencies by a telephone the bridge can be operated in the usual way.

A very great variety of bridge arrangements becomes possible, but the precautions of reducing or eliminating the residuals of the coils become necessary, and great attention must be given to screening the various parts of the apparatus.

Measurement of Very High Resistance.

For high resistance measurement, when the resistance is of the order of megohms, it is customary to use either the method of substitution or alternatively the loss of charge method. In either case a highly sensitive reflecting galvanometer must be employed.

Such galvanometers are of two types, the moving magnet or Kelvin galvanometer and the moving coil or D'Arsonval galvanometer.

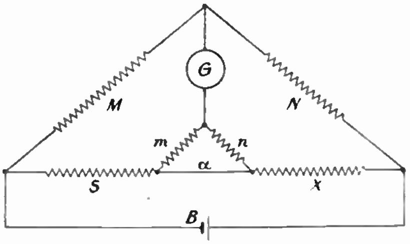

Fig. 10.—ARRANGEMENT FOR KELVIN DOUBLE BRIDGE.

The Kelvin Galvanometer.

In this a double system of small permanent magnets are arranged in two groups, the poles of each group being similarly directed, but each group having its polarity reversed in respect to the other, so that the arrangement is astatic.

The magnets are rigidly attached to a light non-magnetic spindle, which is suspended by means of a single fibre of silk or a very fine quartz fibre, the mechanical control of which is negligibly small.

On this connecting spindle a small mirror is attached, usually between the magnet systems, and when light is sent from a fixed source to the mirror it is returned to a translucent fixed scale so that its deflections may be conveniently observed. The moving system is damped by means of a light vane, usually mounted behind the mirror or at the bottom of the suspension, and this moving in an air

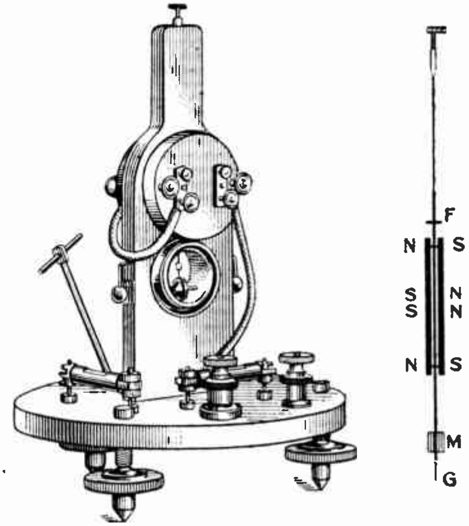

Fig. 11.—The Broca Galvanometer.
This is a modification of the Kelvin instrument.

chamber which fits it closely produces the requisite damping torque by means of air friction.

Each group of magnets is surrounded by a pair of fixed coils at whose centre the magnets can rotate, and if the four coils are connected in series so that the current in the upper pair circulates in the opposite sense to its direction in the lower pair the effect on the magnets will be to produce a deflecting couple in the same direction on both magnet systems.

The restoring or control torque is provided by an external permanent magnet, usually mounted on a vertical rod above the coils so that it may be raised or lowered and turned in a horizontal direction, and in this way the control is varied and the sensitivity altered.

The resistance of such an instrument may be made very high and is capable of some variation by winding the coils in sections and bringing the ends of the sections out to suitable terminals or, alternatively, the coils may be replaced by others of the same dimensions but different resistance. The Kelvin galvanometer has been developed into what is probably the most sensitive current-indicating device which has ever been produced. The early trouble of loss of sensitivity due to the self-demagnetisation of the small magnets has to a considerable extent been overcome by the employment of cobalt steel.

The chief drawback to the general employment of the instrument is its extreme sensitivity to external disturbing fields, which could only be counteracted by the employment of an elaborate and somewhat massive system of shields round the instrument.

By using the new nickel-iron alloys like Mu metal or Permalloy C for the purpose of shielding, a comparatively light shield will now suffice.

The Broca Galvanometer.

Fig. 11 shows a modification of the Kelvin instrument, which is due to Dr. Broca. In this the needle system consists of two comparatively long, thin magnets mounted vertically and parallel to one another. These magnets are magnetised with a consequent pole at their centre so that the whole behaves as a system of very short magnets mounted horizontally without having their defect of a short magnetic memory.

They are suspended by a quartz fibre and a single pair of coils are placed centrally, one on each side of the suspension support, and connected in series so that when current is sent round them a deflection couple is produced by the action of their field on the induced poles in the magnets. The control magnet is carried on a universal joint behind the instrument so that it can be moved and rotated until appropriate control is obtained. It is claimed that with this arrangement the magnets are much more permanent, and by retouching an almost perfectly astatic system can be obtained.

The D'Arsonval Type.

This is much more general. It is practically the inverse of the Kelvin type. In this instrument a fixed horseshoe permanent magnet of tungsten or cobalt steel provides a magnetic field in which a light coil of fine wire is suspended by means of a fine strip of phosphor bronze, which serves both as the mechanical control and also to lead the current into the coil, the lead out being by means of a similar strip below, which is either stretched straight in line with the top suspension or may be in the form of a loosely coiled spiral. A small mirror is mounted above the coil and moves with it and the light from a fixed source is returned to a scale, as already described for the Kelvin instrument.

Ayrton-Mather Variation.

The D'Arsonval galvanometer is made in two forms. In the Ayrton-Mather type the coil is wound in the form of a narrow loop and is suspended between the poles of the permanent magnet without any fixed central iron core. This form of coil was adopted because it can be shown mathematically that the least moment of inertia for the greatest magnetic moment is obtained when the cross section of the coil is two circles touching on the axis of rotation. Such coils, however, are difficult to construct without introducing magnetic controls due to slight magnetic impurities in the wire or its insulation and this reduces the sensitivity.

For this reason the wide rectangular coil is preferred because it can be made to embrace a fixed central iron core, and the sides of the coil are therefore moving in a uniform radial field; magnetic impurities therefore cannot have any serious effect.

Damping.

One of the great advantages of the moving coil instrument is that it can be very easily damped and rendered aperiodic. In the Ayrton-Mather type of instrument the narrow coil can be slipped into a thin silver tube and as this rotates with the coil in the field of the magnet eddy currents are set up in it which produce the required damping torque. Rectangular coil instruments are damped by winding the coil on a light metal former in which eddy currents are similarly produced.

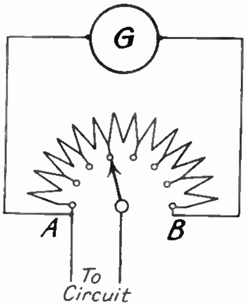

Fig. 13.—ARRANGEMENT OF SHUNT FOR GALVANOMETER.

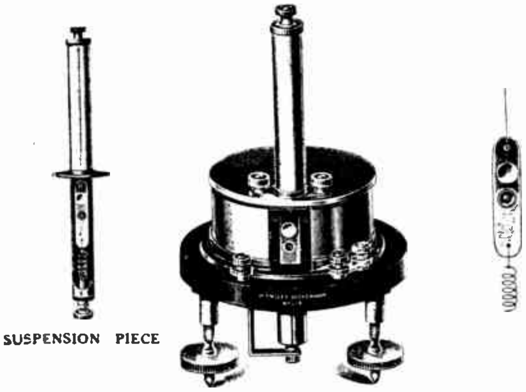

Fig. 12.—THE D'ARSONVAL TYPE OF GALVANOMETER.

Both types of instrument may, however, be satisfactorily damped by shunting the coil with a resistance of such a value that the induced currents generated in the coil itself by its motion in the field produce critical damping. This method necessarily involves some loss of sensitivity.

Shunts.

A sensitive galvanometer is usually used with a shunt in order that its sensitivity may be controlled. This shunt is usually of the Ayrton-Mather or universal type, which consists of a resistance permanently connected across the galvanometer terminals.

A series of tapping points on this resistance are brought out to studs and a rotating brush makes contact to any one of these. The circuit is connected to one end of the resistance A and to the rotating brush, as shown in Fig. 13. Thus when the brush is turned to make contact with the stud connected to the point B on the resistance we have full sensitivity, and when on any other stud the sensitivity is reduced by an amount corresponding to its position.

If, therefore, we choose the resistance of the shunt correctly, it can be made to serve the double purpose of altering sensitivity and rendering the galvanometer dead beat.

The moving coil type of galvanometer has the advantage over the moving magnet type in that it is more robust and less sensitive to external disturbing fields and is much more easily and effectively damped. It cannot, however, have so high a sensitivity as the Kelvin type of instrument and it cannot be built to so high a resistance as the moving magnet instrument, but for general testing work it is a very valuable instrument and does not require magnetic shielding.

BALLISTIC GALVANOMETERS.

In certain methods of measuring capacity and magnetic flux, or whenever it is necessary to measure electric quantity, a somewhat modified type of galvanometer is used. We have in such case to measure a transient current, and the problem is very similar to that of measuring the energy of a rifle bullet when it leaves the muzzle of a gun.

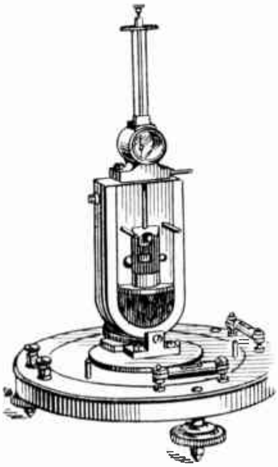

Fig. 14.—The Duddell Thermo Galvanometer.

In order to do this the bullet is fired into a massive wooden bob of a pendulum which has considerable inertia and a slow time of swing. The bullet is retained by the pendulum bob and gives up its energy to it, causing it to swing out over an arc proportional to the energy received.

The electrical problem is treated similarly: the quantity of electricity to be measured is suddenly discharged round the coils of the galvanometer and the first swing or throw of instrument, if it is properly designed, will be proportional to the quantity of electricity discharged. An instrument designed for this purpose is known as a ballistic galvanometer and is characterised by having a moving system with a large moment of inertia as compared with the control or restoring torque or, in other words, it must possess a very long time of swing so that the whole discharge has taken place before the moving system has had time appreciably to move from its position of rest and for maximum sensitivity the instrument should have practically no damping.

It is, however, possible to employ a critically damped instrument for the purpose, and the loss of sensitivity is offset against the considerable saving of time in making a series of observations, but it should be noted that a damped instrument can only be used ballistically when the damping is produced by eddy currents in the manner already discussed.

Kelvin Type.

The Kelvin type of galvanometer can be employed as an undamped ballistic galvanometer by replacing the short, straight magnets by cylindrical bell-shaped magnets magnetised across the axis of the cylinder. In this way the mass of the moving system is considerably increased and the damping reduced, since the magnets rotate with very little air friction; for the same reason the mirror is reduced to the smallest possible dimensions and the damping vane is entirely removed.

Ayrton-Mather Type.

The Ayrton-Mather type of moving coil instrument makes an excellent ballistic galvanometer for condenser work or on circuits of high resistance. When used for this purpose the silver damping tube is removed from the coil and replaced by an ivory one and, obviously, the air friction will be very small with this type of construction. With rectangular coil D'Arsonval instruments the usual procedure is to increase the inertia of the movement by adding to it a series of weights carried on radially projecting arms or by adding a horizontal disc to the suspension below the coil. At the same time the control is reduced by making the metallic suspension very long.

Such galvanometers are usually employed critically damped, and as the circuit may be of so low a resistance as to make the movement over-damped, an adjustable shunt to the magnet is sometimes provided to reduce the working field until critical damping is obtained.

Galvanometers for A.C. Work.

The problem of producing a sensitive galvanometer for alternating currents is not easy, for, as already mentioned, most alternating current instruments follow a square law.

The Dynamometer Principle.

The dynamometer principle can be employed, in which the field is provided by a fixed coil. Within this coil is suspended a moving coil with its plane at right angles to that of the fixed coil, and this moving coil carries a mirror in the usual way for observing the deflection.

When all the coils are joined in series and an alternating current is sent round the combination, the moving coil is deflected by a torque which is proportional to the square of the current.

Such instruments, however, have several disadvantages, for in order to obtain sufficient sensitivity the coils must be wound with a comparatively large number of turns of fine wire. The impedance of the instrument is therefore high and a fairly large voltage is necessary in order to send the current through it, and this may lead to troublesome electro-static effects.

Moreover, the introduction of a highly inductive instrument into the circuit may be very objectionable and, lastly, the instrument is very appreciably affected by external disturbing fields.

The D'Arsonval Principle.

Alternatively, we may make an instrument on the same principle as the D'Arsonval galvanometer, replacing the permanent magnet by a laminated electromagnet excited by the alternating current. Very sensitive instruments of this type have been built, but difficulty arises because of the phase difference which exists between the gap flux and the current in the moving coil, and here also the impedance of the instrument may be high.

The Duddell Thermo Galvanometer.

The thermo galvanometer devised by the late Mr. W. Duddell is an excellent solution to the problem, particularly where high frequencies are to be employed. In this instrument shown in Fig. 14 the principle of the radio micrometer, invented by Professor Boys, has been adapted.

A circular permanent magnet has a small gap between its poles, and suspended in this gap by means of a quartz fibre is a narrow loop of bare copper wire, which is closed at its lower end by a minute thermo couple of two special alloys which give a high thermo E.M.F. for a small rise of temperature. Immediately below this system Duddell arranged a little heater consisting of a few millimetres of very fine resistance wire, or, in the case of a high resistance heater a platinised quartz thread, and through this the current is passed. The passage of the current heats the wire and the heat produced is communicated to the thermo couple by radiation and convection. The thermo E.M.F. set up sends current round the wire loop, which is deflected like the coil of a D'Arsonval galvanometer, and its movements are observed by a mirror arrangement.

The original radio micrometer of Professor Boys is preserved practically in its entirety in this instrument, the only variation being that of adding the minute heater. The instrument is obviously very temperature sensitive, so that the whole movement has to be buried in a massive block of brass to delay the effects of external temperature change. An outer wooden cover affords further protection.

The thermo couple consists of two alloys, both of which are bismuth rich and are therefore strongly diamagnetic. They are therefore screened from the stray field of the permanent magnet by being surrounded by an iron block mounted below the permanent magnet.

As a sensitive alternating current galvanometer it gives excellent performance. The resistance is altered by changing the heater, which is a self-contained unit and easily removed, and with any given heater the sensitivity can be somewhat altered by advancing it towards the junction above it, a screw motion being provided for this purpose. Since the heater is simply a few millimetres of straight wire of very small diameter, the inductance and capacity of the instrument is very small, so that when calibrated with direct currents it may be used in high frequency circuits.

TUBULAR AND PANEL HEATERS

By E. H. FREEMAN, M.I.E.E.

IN the early days of electric heating the only form of heater used was the electric fire consisting generally of a coil of high resistance wire wound on a former or frame of some refractory material and fitted in front of a reflector such as that of the ordinary bowl fire. Such electric fires attained their designed temperature of 1,500° to 1,600° within a few minutes and were and are extremely useful in providing heat within a confined area and in a short time.

The heat given out was mainly radiant heat, i.e., of a kind that does not heat the air through which the heat rays pass but only the objects on which the heat rays impinge. A proportion, perhaps 30 per cent., of the heat is used in heating the air and the effect of such heaters in warming a room as distinct from the objects in it was not very satisfactory.

Convector type heaters (of which the so called hot water radiator is the most common example) on the other hand act mainly by warming the air of the room and are more effective than fires when it is desired to obtain a generally even temperature rather than to warm actual objects.

Both results are desirable under varying conditions and usually both together as a warmed room with no radiant heat is apt to feel stuffy whilst the comfort of a definite source of radiant heat such as a coal fire or an electric radiator is a commonplace.

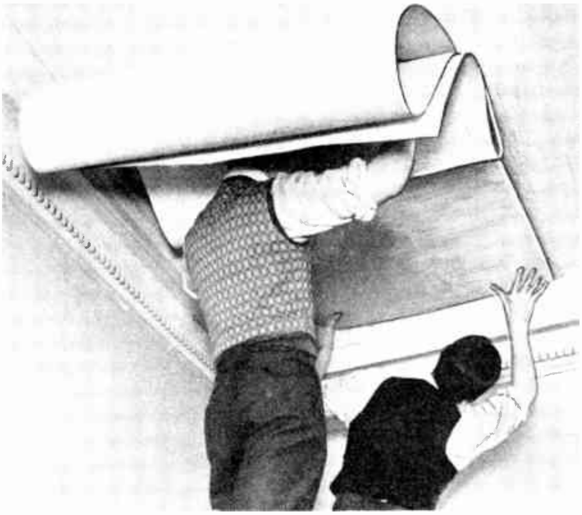

Fig. 1.—" DULRAE " HEATING PANEL IN COURSE OF ERECTION.

Early Forms of Convector Heaters.

The limitations of radiant heat were realized and early forms of convector heaters designed to warm the air of a room were definitely adaptations of the ordinary hot water radiator. Some of these had an independent boiler fixed below, steam passing round the passages of the radiator and after cooling, condensing and passing back to the boiler to be again converted into steam. Others had an immersion heater in the main body of the radiator and a hot water circulation in the radiator similar to that in the ordinary centrally heated system of hot water radiators.

Electrically Heated Boilers.

A third application of electricity to such local heaters was the substitution of electric immersion heaters in the central boiler these replacing the coke or oil as a source of heat. This system does not so conveniently allow the control of the heat in individual rooms by thermostats as either of the other systems and it still involves carrying the usual system of hot pipes through the building involving waste of heat in many places and consequent loss of efficiency. It is mainly of service where current can be obtained at very low cost at certain hours but not at others as it lends itself to storage of heat during low cost periods the heat being subsequently used as required at times when current would be comparatively costly.

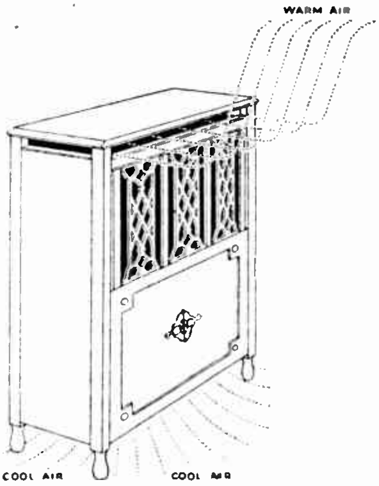

Fig. 2.—Air Convector.

Low Temperature Heaters.

The growing demand for heating apparatus of this kind, operating as most of them do with a surface temperature of 100° to 150° F., has led to the invention of several types of apparatus all designed for local control and each suitable in its own way for varying conditions. Of these the best known are as follows :—

(1) *The Air Convector.*—This consists of a heating element enclosed in a suitable casing with vent holes above and below, the air passing in at the bottom being warmed as it passes over the heated wires, and passing out at the top to warm the room. This type is illustrated in Fig. 2.

(2) *Tubular Heaters.*—These are probably the most popular form, consisting of tubes about 2 inches diameter, inside which is a wire heating element carried on a mica or other support and effectively supported clear of the tube. The element warms the adjacent air which in turn warms the surface of the tube and gives a large surface of warmed metal which distributes the heat into the room, partly by radiation and partly by convection.

(3) *Panel Heaters.*—There are various kinds of such heaters designed for embedding in walls or ceilings. The best known of these are the Electrorad panel and the Dulrae panel.

The former has heating elements enclosed in a flat cast iron housing of varying size to meet varying conditions which heats the exposed surface of the housing on much the same principle as the tubular heaters. An example of this is shown in Fig. 3.

The Dulrae panel on the other hand consists of heating wires actually embedded in the substance of the panel which is quite thin and can be laid over the surface of the wall or ceiling more or less like a wallpaper. See Fig. 1.

Both these panel heaters need heat insulating materials behind them to ensure that the heat is projected into the room and not into the wall or ceiling behind.

(4) *Morganite Heaters.*—These heaters represent another form of panel heater and consist of flat panels built up of a semi-conducting material with insulating material surrounding this, the entire panel heating up to a temperature well above that of the other panel heaters. These are for use where a greater degree of radiant heat is desirable, the surface temperature rising to 450° F.

Relative Advantages.

All these types have their uses and advantages. Types 1 and 2 (air convectors and tubular heaters) are easily installed, can be altered in position or loading with very little difficulty and are economical in first cost. They are exposed in the rooms and to this extent their use may be a disadvantage in certain conditions.

The Electrorad ceiling panel is more expensive than these but can be completely embedded in the ceilings if desired or formed into a projecting panel as may be convenient for decorative treatment.

The Dulrae panel is still more expensive but is more easily attached to the ceiling although special precautions need to be taken in providing a suitable backing of insulation. The projection or rather

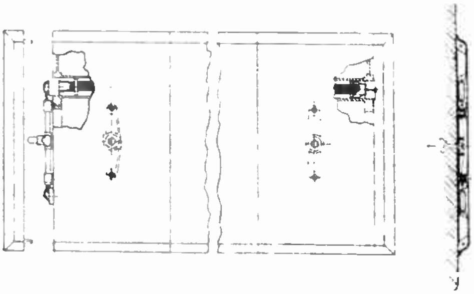

Fig. 3.—ELECTRORAD PANEL.
Showing details of construction.

increased thickness of ceiling is very slight but the effect of water on the enclosing material is likely to be considerable and might involve replacement.

Either type of ceiling panel would require the redecoration of the room in the event of alterations being required.

The remedy for avoiding risk of alteration is of course to provide ample margins of heat in the first place but this may be expensive. The use of all such heaters has now become sufficiently widespread for the proper design of any installation and there should be no difficulty in carrying out any scheme with any of these systems without any need to face future alterations.

Temperature Rise to be Allowed.

The normal external winter temperature in this country is about 40° and rarely falls below 30° except for short periods. This being so standard practice in heating design has adopted 30° as the normal minimum and heaters are installed to raise the internal temperature to 55°, 60° or 65° according to the conditions. This ultimate temperature is a matter of taste and also of circumstance, an operating theatre for example needing to be maintained at a higher temperature than a garage.

For ordinary domestic schemes and also for offices, factories, etc., the heating apparatus should be installed suitable for raising the temperature about 30° to 35° and even if the full load of heaters is not actually fixed wiring should be provided on this basis at least.

Load Required.

The actual load required on the heaters to achieve this result is a matter for rather complicated calculation and it is impossible in a brief article to go fully into details. In close designing many factors have to be taken into account. Thickness of walls, floors and ceilings and details of their construction; whether walls are exposed on the North, South, East or West; relative areas of window or skylight; degree of ventilation necessary (i.e. number of changes of air per hour); temperature of adjacent rooms—all these have a considerable bearing on the result as may also the heating effects of the lighting units. As a rough guide it is rarely safe to allow less than 1 watt per cubic foot and rarely necessary to need more than 1½ watts, i.e. a room 20 feet by 15 feet by 10 feet high would need probably not less than 3 K.W. or more than 4½ K.W. This load might be distributed in any way convenient though it is usually desirable to concentrate a considerable proportion of it near the windows.

Thermostat Control.

If thermostat control is provided the loading is less important from the point of view of economical working than if hand control is relied on. The thermostat switch, of which there are a number of reliable types available, can be set to operate at any selected temperature within a wide range—say between 45° and 70°—and automatically switches the heaters on or off as the temperature falls or rises. Such thermostats can be supplied to operate within a degree or two of the selected temperature and can thus maintain the room at a constant temperature which need not vary more than say between 58° and 62° if the selected temperature is 60°.

Thermostats can be fixed at any convenient position in the room but should be well out of any direct draught.

Running Cost.

As a broad generalization it can be assumed that with current at ½d. per unit the electric scheme can be compared favourably with an ordinary central heating oil or coke fired boiler scheme.

CLASSIFIED KEY

ELECTRICAL MACHINERY.

Direct Current.

Alternating Current.

GENERATION AND DISTRIBUTION.

INSTRUMENTS AND METERS.

WIRES, CABLES AND WIRING SYSTEMS AND METHODS.

(*See also Installation Work.*)

LIGHTING AND ILLUMINATION.

DOMESTIC APPLIANCES.

(*See also Wires, Cables, etc.*)

INSTALLATION WORK.

OPERATION AND MAINTENANCE WORK.

INDUSTRIAL USES OF ELECTRICITY.

ELECTRICAL CALCULATIONS AND THEORY.

CAR ELECTRICAL EQUIPMENT.

THEATRE AND CINEMA WORK.

WIRELESS AND GRAMOPHONES.

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PRACTICAL
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Intended for Electric Lighting and Power Engineers.
Electricians and Wiremen. Wireless Dealers.
Students, Apprentices and Improvers in all Branches
of the Electrical and Wireless Industries

General Editor
EDWARD MOLLOY

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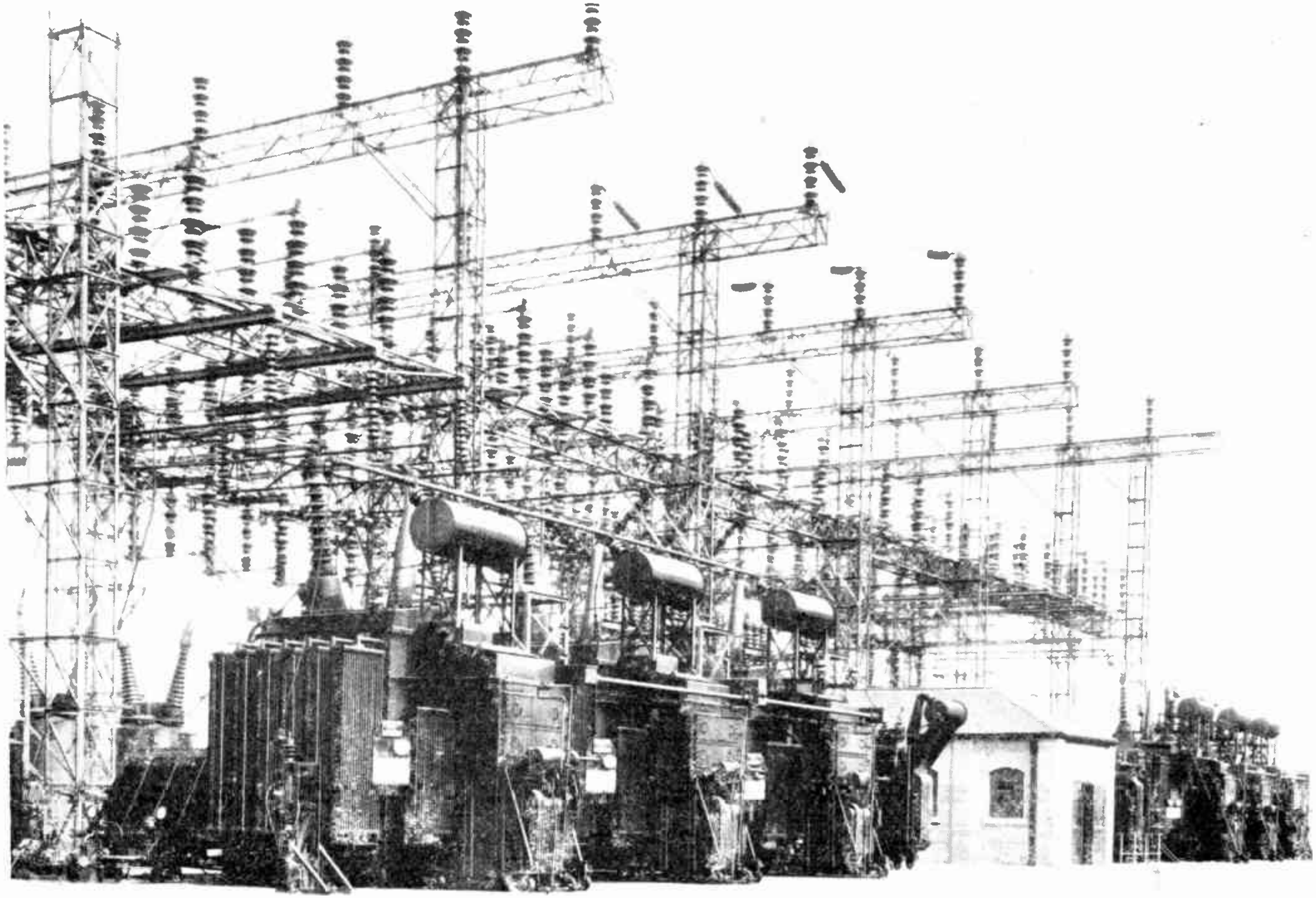

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PREFACE TO VOLUME V

ELECTRICAL Engineering is a fascinating profession. Practically everyone who enters this profession does so because he has a natural inclination towards engineering. It is comparatively rare that a boy is forced to become an engineer against his will. It is perhaps still rarer that a man takes up engineering solely with the object of making money.

The practice of Electrical Engineering is so interesting to the people who are engaged in it that they are apt to lose sight entirely of the commercial side. The danger of this is that people with a well-developed business instinct are often able to achieve controlling positions in the industry because the engineer has been too wrapped up in the technical side of his work to acquire the elements of business knowledge which are so necessary for the man who wishes to get the best return for his daily work.

In the present volume will be found a most interesting article, " How to Start an Electrical Business," written by Mr. D. Winton Thorpe, A.M.I.E.E., dealing with the Business Side. Mr. Thorpe combines with his professional attainments a broad outlook on the human side. However impatient the engineer may be with "sordid commerce," it must be admitted that whatever his position in the industry, he only lives by selling his work to other members of the community.

No work on Electrical Engineering would be complete without an adequate reference to the Institution which has done so much to raise the status of electrical engineering to a profession, viz., The Institution of Electrical Engineers. An interesting article on this subject will be found on page 1814. Another Association which is of special interest to those engaged on the Contracting side of the Industry is the Electrical Contractors' Association. In the article dealing with this important association will be found Standard Conditions of Contract and Tender for electrical work. Every electrical engineer who aspires to a responsible position should be familiar with the requirements and conditions set out in this section.

Another article which comes outside the strictly technical aspect is that written by Alderman Tweedy-Smith under the title of " Law Relating to Electrical Engineers and Contractors."

It is difficult to select from the remaining sections of this volume those which are likely to be of most direct interest to the reader, so varied is the work which an electrical engineer may be called upon to do in the present highly developed state of the industry.

"Power Factor Correction Apparatus," by Professor Miles Walker, M.A., D.Sc., F.R.S., is of particular interest to those engaged on the generation or distribution side of the industry. The same applies to the article on "Electrical Tariffs," by Mr. H. W. Johnson.

Those interested particularly in the more scientific aspect are referred to Dr. Norman Campbell's article on "Photo-Electric Cells"; Mr. C. A. Quarrington's article on "The Cathode-Ray Oscillograph," and Mr. C. A. Jolley's contribution on "Laboratory and Test-Room Apparatus."

An article of special interest at the present time is that by Mr. R. F. Markham, Cable Engineer to Messrs. Johnson and Phillips. It deals with the "Erection of Transmission Lines and the Laying of Distribution Cables," and presents a masterly survey of this important subject written from the special viewpoint of the practical engineer.

No effort has been spared to make this work representative of best modern practice, and special thanks are due to the contributors who have placed the results of their practical experience at the disposal of our readers. In particular we should like to thank Messrs. Johnson and Phillips, Ltd., the well-known underground cable and overhead line engineers, for much of the information given in the article entitled "How Current Reaches the Consumer." The tables in this article were taken from "The Economic and Engineering Features of Electrification in Rural Areas," published by Johnson and Phillips.

During the passage of this work through the press many valuable suggestions have been received from people in the electrical industry, and wherever these could be usefully included this has been done.

Any suggestions which readers may make for the improvement of this work in later editions will receive careful consideration. Communications should be addressed to the Editor, c/o George Newnes, Ltd., 8-11, Southampton Street, Strand, London, W.C.2.

E. M.

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