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TESTING,
FAULT LOCALIZATION
AND
GENERAL HINTS
FOR WIREMEN

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INTRODUCTORY

At the outset the Author wishes it to be distinctly understood that the present book has no pretensions to the title of text-book on electrical testing, but is intended rather as a brief summary of some unorthodox tests, hints on locating trouble, etc., which can be conducted quite simply by the average wireman, and, for the greater part, without the aid of complex or expensive apparatus.

For obvious reasons, little or no attempt has been made at explaining the "why" and "wherefore" of the various methods, but rather "how" they may best be put into operation with the facilities commonly possessed by the class of reader for whom these manuals have been written.

J. W.

TESTING, FAULT LOCALIZATION AND GENERAL HINTS FOR WIREMEN

(1) FIRST PRINCIPLES

Almost all testing and fault localization which come within the scope of a wireman or working electrician's daily routine, involve the determination of current flow, either in cases where it should not exist, as, e.g., through a fault in the insulation of a cable or piece of apparatus, or, where such flow is legitimate but non-existent, as in the event of a disconnexion.

Thus, in testing insulation we measure the magnitude of the current passing through the insulation, and, from it, determine the value of the latter in terms of its ohmic resistance. Again, in testing for disconnexions, or similar faults, the absence of current flow is an indication of the nature of the fault.

It is a well-known fact, even to the tyro, that, given a source of current having a definite electromotive force, if we provide a path for that current, whether of high or low ohmic resistance, then there must be a definite flow, the magnitude, or "amperage" depending, where direct currents are concerned, on the originating E.M.F., and the ohmic resistance of the path. In the case of alternating currents we have to reckon with the additional factors, self-induction and capacity, which may, however, be shelved for the present.

To detect or measure such currents we require suitable apparatus, and, thanks to the many familiar

characteristics of an electric current we have an ample choice, ranging from delicate and costly laboratory instruments, to a compass needle and coil of wire, or even the human sense of touch. Another useful sense which can be pressed into service as will be seen later, is that of hearing, and an ordinary telephone receiver is one of the most useful accessories a wireman can possess, since, with a little practice it is capable of giving not only qualitative, but approximately quantitative results, and the intelligent user will find it of considerable service in indicating both the nature and extent of various classes of fault.

Before proceeding further, I wish to impress upon the reader the necessity for cultivating the faculty of deduction, or inference. There are many workers who, faced with a problem in the shape of a fault in, or failure of some electrical gear, are quite at a loss as to how to proceed in localizing the trouble. The average text-book gives reams of information on the subject of measuring resistance and insulation, locating breaks in conductors, "loop" tests for "earth" faults, etc., etc., but leaves all but the expert reader entirely in the dark on the subject of diagnosis, or to put it more simply, the discovery of the disease by its symptoms.

A little forethought at an early stage will often save hours of laborious testing on the "trial and error" principle, and is a detective instinct which every wireman desirous of bettering his position should cultivate to the utmost.

To cite a practical illustration, the man who, when certain lights are suddenly extinguished, can say to himself—"That's the third fuse from the left, in No. 3 Distribution Board," or, again, in testing a telephone circuit, "The other man can't hear me, but I can hear him; probably a transmitter circuit fault in my instrument"—is worth ten who would proceed to a lengthy and laborious system of point to point testing or investigation of the trouble.

An almost equally valuable asset is the faculty of observation, well developed. Take care to note every feature in connexion with your work; ask yourself the "why" and "wherefore" of everyday happenings in the course of your occupation, and, given a fair memory, you will be able to treasure up a storehouse of personal information in connexion with your work which will prove invaluable in after life.

To make the matter quite clear, let us take one of the simplest possible cases which come within the jurisdiction of a wireman and analyse the mode of procedure. An ordinary electric bell fails, and our man is called in to remedy the trouble. His reasoning should be after this style: "Was the failure sudden, or gradual?" If the former, it is probably a broken wire; if the latter, a case of weak batteries. Having thus settled the preliminaries by judicious questioning of the client, we will assume the former to have been the symptom in this particular case. Prove entire absence of current by disconnecting the circuit at any convenient point, the push, for instance, and placing the two ends of wire on tip of tongue. The characteristic taste will suffice to settle this point. If absent, seek the most vulnerable point in the installation, frequently a helix, introduced as a hinge between door and jamb when the push is fitted to the door itself, or, failing this, any point in the wiring exposed to the ministrations of the housemaid's dustpan and brush. Failing this again, we have the inherent tendency of battery terminals to corrode, or the possibility of a badly fitting contact screw at the bell trembler having worked loose under the vibration of the armature, to fall back upon. There are other possibilities, of course, but the procedure thus far analysed, serves as a general illustration of the first principles of deduction in electrical testing and fault localization, and we will proceed to a consideration of other matters equally relevant.

(2) TESTING BY TELEPHONE

As already intimated, the ordinary telephone receiver, which has a resistance ranging from 60 to 150 ohms, is one of the most useful pieces of apparatus which the average wireman can possess. The human sense of hearing is very acute, and can, by the aid of the telephone, detect the presence of currents far too minute to produce a visual indication on any but the most sensitive galvanometer or other current indicator. In proof of this assertion, take a telephone receiver, and, holding it to the ear in the usual manner, get an assistant to tap the connecting wires or ends of the flexible cords on the terminals of a single wet or dry cell. The result will be a loud click, for each "make" or "break" of the circuit, produced by the alternate attraction and release of the thin sheet-iron diaphragm.

At this point it may be stated that telephone receivers made up on what is known amongst telephone experts as the "head-gear" pattern are the most convenient for ordinary testing since the hands are left free for manipulation of the wires and connexions generally. The "head-gear" receiver is a small self-contained type, embodying "ring" magnets, instead of the usual straight-limbed pattern, the whole being mounted at the extremity of a curved steel band, which passes over the head, and automatically holds the receiver in position against the ear of the user. The connexions to the receiver terminals should be made by means of specially flexible leads, or "receiver cords" as they are termed, since any stiff or rigid conductor tends to set up extraneous noises when moved, and thus detract from the sensitiveness of the apparatus.

(3) CONTINUITY TEST

As already intimated, any circuit can be tested for continuity with the aid of the receiver and a source

of current, such as a battery of two or more cells. All that is necessary is to connect battery and receiver in series, and apply the two free wires to the points which form the terminals of the circuit under test, e.g., one feeding lamps from a distribution board. The arrangement is shown in Fig. 1, where

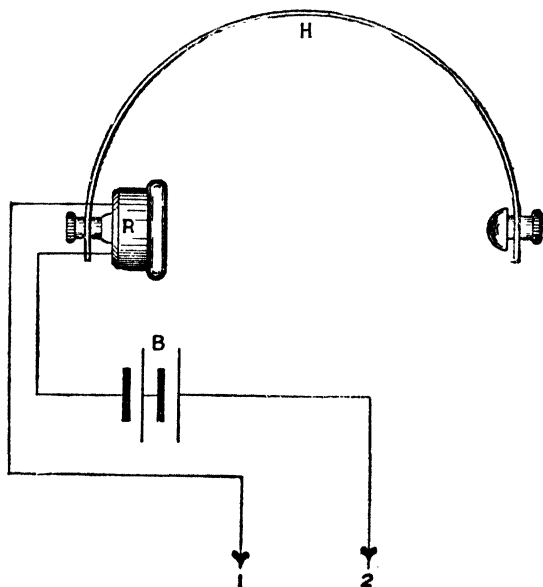


FIG. 1

R is the receiver, mounted on its head-band *H*, and connected in series with the battery *B*, to the two testing leads, 1 and 2, which latter may conveniently be finished off in the shape of points of steel or other hard metal, thus enabling contact to be made through a non-conducting film of dirt, enamel, lacquer, paint, or similar covering of the metal to which it is desired to apply the test.

It will be seen that the arrangement affords a very convenient method of locating a break or disconnexion by "point to point" testing. Thus, assuming a disconnexion in one coil of a motor armature. We apply our testing leads 1 and 2 to each pair of commutator segments in turn, until two are found between which there is no responsive click when the metal points are brought into contact with them. The disconnected coil will be that ending in these two segments, and is thus easily traced.

Another great advantage of this simple method of continuity testing is that, to the practised ear, an intermittent, or imperfect contact, due to a loose terminal screw, or a dirty contact between lamp-cap and plunger for example, can be detected by the rattling or frying sound set up in the receiver. Any loose or imperfect contact in a telephone circuit, possesses the characteristics of a microphone, or sound intensifier, and responds to the natural vibrations of the fitting, walls, floor, or ceiling of the room in which it exists. After a little practice, therefore, the wireman will be able to instantly detect any such defect, on making connexion with his testing leads.

(4) INSULATION TEST

Similarly, the telephone receiver may be used for testing the insulation of circuits, apparatus, fittings, motors, etc. For this purpose the same simple arrangement is employed, but it is desirable to increase the battery power or voltage of the source of current, in order to put the insulation under test to a greater strain, and thus break down any weak points which may exist. Incidentally, increasing the testing E.M.F. also adds to the sensitiveness of the test since the responses in the receiver are more readily followed.

To this end, any convenient supply voltage may be

used, and a resistance introduced into the circuit to keep the current within safe limits in the event of a fault. A convenient resistance for this purpose may take the form of two or more incandescent lamps, rated for the same voltage as that available for testing, and connected in series with the receiver and source of current as shown in Fig. 2, where R is the receiver as before, G the source of current, or supply mains, and L, L, L lamps inserted as resistances to protect the receiver. 1 and 2 are the testing leads, one of which is connected to any convenient "earth," such as the metal frame of the switch, lamp-holder, motor, or other gear, or the lead-covering or armouring of a cable.¹ If a general insulation test to earth be conducted the best "earth" connexion is obtained through any near-by water-pipe. The remaining test lead is then brought into contact with the terminals of

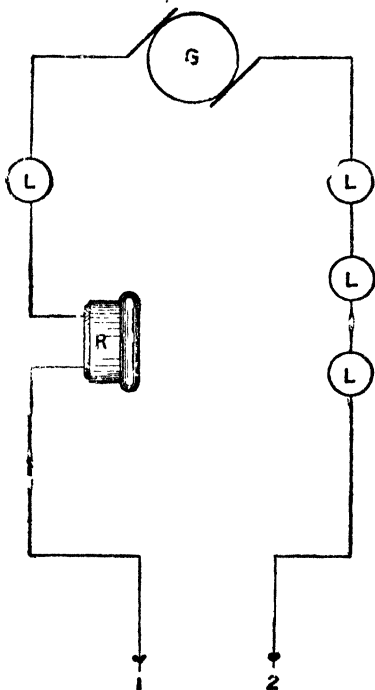


FIG. 2.

¹ In using a supply system, one side of which is permanently "earthed," care must be taken in connecting this same pole of the system to the testing "earth."

the apparatus, or conductor of the cable. If a click results on making the connexion, it does not necessarily follow that the insulation is at fault. The circuit should be left completed for half a minute or so, to enable the system to become electrostatically charged. If, then, on breaking circuit with the receiver, there is an equally loud click, the insulation is at fault, and requires investigation.

In this test for insulation it is important to bear in mind that the click on *breaking* circuit is a correct indication, and not that which follows the initial contact of the testing lead with the terminal, the reason being that any mass of conducting metal acts similarly to the plate of a condenser, and, if of any magnitude, requires an appreciable static charge to raise it to maximum potential. If the insulation be perfect, subsequent making and breaking of the receiver circuit will produce no appreciable sound. It is important to bear this fact in mind because a distributing network of conductors in a building, for example, will give very different results under this test, to a single switch or fitting tested independently; whereas the latter will produce no appreciable sound in the receiver, even at "make," the latter will respond with quite a loud signal which, however, if due time be allowed, and the insulation be in order, will have disappeared on breaking circuit.

The Author introduced this system as a rough workshop method of testing insulation many years ago, and it is still working satisfactorily to-day, the operator in attendance being sufficiently expert by dint of constant practice to state the approximate insulation of any familiar article under test, within five megohms.

(5) FAULTS ON ALTERNATING CURRENT CIRCUITS

Another extremely useful application of the telephone receiver is in the detection of "earths" or

"short-circuit" faults on alternating current circuits. Alternating currents of the usual supply frequency, have a characteristic note, or "hum," which can be reproduced in a telephone receiver by electro-magnetic induction. Referring to Fig. 3, if we take two similar coils of wire, *B*, *C*, connect one, *B*, to a source of alternating current, *A*, and the other, *C*, to a receiver, *R*, the coils being placed with their axes in line, we shall be able to hear in *R* the hum of the current alternations in *B*, reproduced with a volume depending on the distance, *d*, between the two bobbins.

Applying this principle in practice to the localization of "earths" and "short-circuits" is impossible

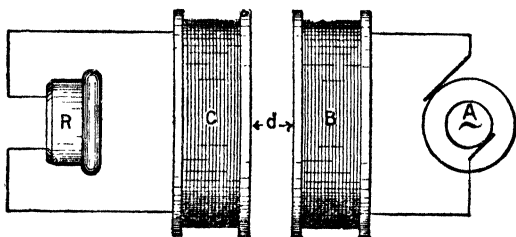


FIG. 3.

under conditions so favourable as those depicted in the figure, since the circuits we require to test usually take up a straight line formation, and the mutual induction between primary and secondary is consequently limited to the reaction between two comparatively short sections of two single turns of infinite radius. This drawback may be compensated to an appreciable extent by making the current density in the faulty circuit as high as possible, and arranging the secondary or test coil with as long a base line as practicable, thus ensuring maximum parallelism between the coil connected to the telephone receiver and the circuit under test.

The test or "search" coil, *C* (Fig. 4), is made up in

the form of an equilateral triangle, with as long a base, ab , as practicable. Its winding is connected to the receiver R , and should preferably have as many turns of wire as possible, giving a total resistance approximately equal to that of the receiver. The principle of the test will be readily understood. An alternating current from the generator A , flowing round the circuit c, d, e, f , will induce a secondary current in the base turns, a, b , of the coil C , and set up a hum in the telephone receiver R , so long as the base ab is

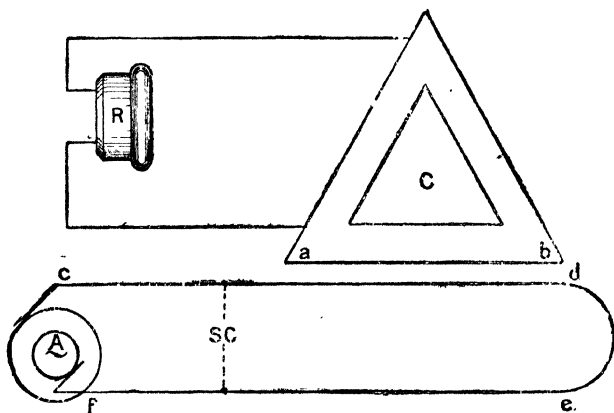


FIG. 4.

in close proximity and parallel to one of the conductors, c, d , for example, but comparatively remote from the return conductor, e, f . A short circuit, as at $S.C.$, shunts the current back to the generator A and leaves that portion of the circuit beyond it comparatively inert, so that it has little or no effect upon the search coil C . The latter is thus moved along parallel to one conductor until the hum suddenly decreases in volume, or disappears entirely, thus indicating the position of a short-circuit fault.

To locate an "earth" on one conductor, one

terminal of the generator *A* is connected to earth, and the other joined to the faulty conductor, when the same diminution or cessation of sound in the receiver *A*, indicates that the fault has just been passed over by the coil. In applying this test to circuits made up of twin or concentric cable, the "earth" test only is available, since the induction is neutralized, and there is little or no effect upon the search coil. It is also unsatisfactory in the case of conduit, or armoured conductors, owing to the screening effect of the surrounding metal, but has, nevertheless, proved extremely serviceable in locating faults both on a large and small scale.

Where the length of the circuits is limited, and circumstances permit of the search coil being brought into very close proximity to the conductor under test, a battery and buzzer, or induction coil and interrupter may be substituted for the alternator *A*, as a primary source of testing current; the telephone receiver being responsive to a wide range of notes will pick up a whole series of induced vibratory currents, from the rattle produced by an electric bell trembler to the screech of a high-pitched reed.

(6) BRIDGE TESTING

Our telephone receiver can also be substituted for the usual galvanometer in ordinary Wheatstone bridge testing, but, where the value of the resistance under test is such that an exact balance cannot be obtained, the telephone will never be wholly silent when the battery key is operated. A very exact adjustment is, however, possible when using the simple "metre bridge," consisting of a stretched wire and slider, and it is possible, in such case, to obtain an adjustment for the latter which will produce no sound in the receiver on pressing and releasing the battery key. When a telephone receiver is thus used the ordinary galvanometer key can be dispensed with.

(7) THE MEGGER AND ITS USES

One of the most frequent and important tests which the wireman is called upon to make, is that of insulation resistance, either of a motor or dynamo, a switch, or other accessory, or a complete wiring installation for electric light or power. There are several ways of conducting this test, but the most popular, by virtue of its time and labour-saving characteristics is undoubtedly that involving the direct-reading "Megger," an ingenious piece of apparatus, comprising, so far as it concerns the actual user, a graduated dial, a crank handle, and a pair of terminals. Having connected one of the latter to some conducting portion of the circuit or apparatus which is to be tested, and the other to a convenient "earth," which may take the form of a water pipe, conduit, or metal frame, casing, etc., of the article to be tested, the handle is turned at a gradually increasing speed, until it is felt to slip, or offer no resistance, a sign that the maximum voltage is being generated. The required insulation resistance is then read directly on the scale.

I do not purpose entering upon a description of the construction, or working principle of this invaluable piece of apparatus; it is fully described, and its theory explained in most modern text-books on the subject of testing. There are, however, one or two points in connexion with its use which should be understood and recognized by the average wireman.

In the first place, the current generator or dynamo portion of the megger has a permanent magnet field, and it must obviously be set down in a position remote from any extraneous disturbing force, such as that created by the poles of a dynamo or motor. A warning to this effect is attached to the directions for use.

Next, bear in mind that the megger is a direct-reading instrument; it takes no account of length

(in the case of circuits) or area (in the case of connecting metal) but will register the actual insulation resistance, whether the circuit under test be a mile or a yard long, or the particular piece of apparatus tested be a dynamo or a ceiling rose. This failure to differentiate between objects of widely divergent dimensions is at first rather puzzling to the user previously accustomed to testing insulation by battery and galvanometer.

Another point to remember is the conductivity of the human body. Thus, in testing a piece of plant or apparatus, or a series of fittings, prior to fixing, it is often convenient to hold the testing leads in position whilst an assistant turns the handle. In all cases the connecting leads themselves should be well insulated, as determined by a preliminary test, with their ends held free, and in no case should the user handle the exposed metal of the conductors, or an error will creep into the result, the magnitude of which will largely depend upon the surface resistance of his skin.

As regards speed of turning, it is desirable always to maintain a maximum steady rotation of the handle, just at or about the critical speed at which the driving clutch slips. For all ordinary purposes the indications will then be free from error due to the electrostatic capacity of the circuit or article tested, since the E.M.F. of the testing generator will then be constant within 0·5 of one per cent.

(8) SURFACE LEAKAGE AND ITS BEARING ON INSULATION

The wireman desirous of arriving at correct results in insulation testing should be thoroughly conversant with the subject of what is known as "surface leakage," and its possible influence on any results which he may obtain in practice. There is little doubt that surface leakage has been responsible for a large

proportion of those installations which are rejected by the supply company's inspector as not up to the insulation standard demanded by regulations.

The inexperienced man is prone to imagine that having stripped back the insulating covering from the conductor for a short distance, and inserted the bared end of the wire or strand into the terminal, under the connexion screw provided, his task is complete, and, if the resultant test be not up to specification, he, personally, is blameless in the matter, whereas in nine cases out of ten he is directly responsible for the trouble.

In order to thoroughly grasp the following explanation it is necessary in the first instance to understand that the terms "conductor" and "insulator" are purely relative, and not separate and distinct qualities, as students of elementary electricity are apt to gather from the definitions put before them. Under certain circumstances, any so called insulator may become a conductor, and, conversely, many conductors may, under appropriate conditions, be classed as insulators. The terms are purely relative, and the dividing line none too well marked, at any rate from the tyro's point of view.

To cite a practical example. Take glazed porcelain, as used in the manufacture of switches, ceiling roses, etc. Given a sound glaze it is one of the best insulations known for this class of accessory, and will yield "Infinity" when tested with a high voltage megger. Expose the same fitting to a jet of steam, or any similar condition conducive to the deposition of moisture on its surface, and, on again testing, the insulation will be found to have fallen considerably; may, in fact under certain conditions have decreased to a few hundred ohms, or even less. In such case it is "surface leakage," through the semi-conducting film of moisture which you are measuring, and not the true insulation of the porcelain.

Similarly the woven tape, braiding, and preserva-

live compound, which serve as a protective coating to most rubber insulated conductors, are of a semi conducting character, and, if left in permanent contact with the metal core, form a shunt leakage path, outside the true rubber insulation, which will materially lower the general insulation of the section of which they form part. It cannot be too strongly impressed upon the wireman that every protective tape or braid on a V.I.R. conductor, left touching the actual metal, is a source of leakage, and may, in the aggregate, lead to rejected work.

Wherever an insulated conductor is bared, or its insulation stripped back for the purpose of making a connexion, both *tape* and *braid* should be removed for the space of at least half an inch, leaving the surface of the rubber alone exposed. To remove the tape sometimes presents some difficulty, owing to its having been vulcanized into the surface of the underlying rubber, but application of a rag soaked in benzine or petrol will soon effect a cure, and enable the tape to be peeled back quite clear of the rubber underneath.

In this connexion, "proof" or "bull-dog" tape, or, in fact, any textile material, is equally liable to set up surface leakage, if not at first, then subsequently, when its fibres have absorbed the necessary moisture from the atmosphere.

(9) THE "GUARD-WIRE" PRINCIPLE IN INSULATION TESTING

The governing principle of the usual text-book and laboratory method of testing insulation resistance is outlined in Fig. 5, where G is the galvanometer, B a battery of suitable E.M.F., C the cable under test, R a standard high resistance of known value, S a two-way switch, and E an earth or return connexion. Avoiding details, the general conduct of the test is as follows. The switch S is first placed on

stud *a*, and the resultant deflection *D*, on the galvanometer *G*, carefully noted. This will be proportional to the current flowing from battery *B*, through the known resistance *R*. Switch *S* is then moved over to *b*, and a second deflection, *D*1, obtained, proportional to the current passing through the insulation to earth *E*. The calculation of the insulation resistance of the cable or apparatus under test is then

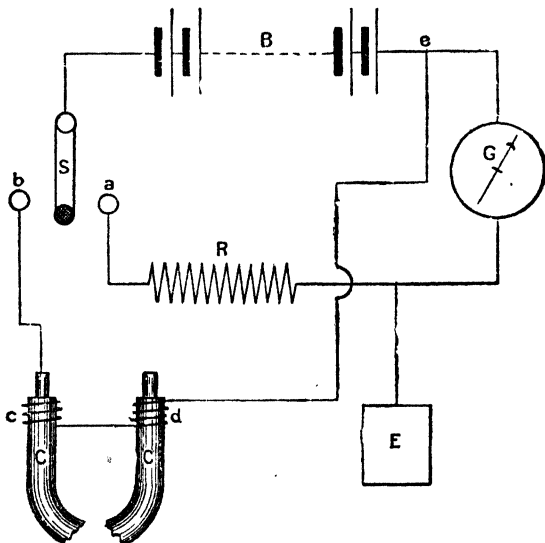


FIG. 5.

simple inverse proportion sum, and may be expressed thus :

$$D1 : D : : R : X \text{ (the insulation required).}$$

Reverting to the subject of surface leakage, it will be apparent that any conducting, or semi-conducting path between the conductor of cable *C*, and the surrounding armour, lead sheathing, conduit, or other medium which immediately envelops the exterior of

the insulation, will constitute a shunt leakage path for the current from battery B to earth at E , the current passing along which will amplify that actually passing through the insulation of the cable, and lead to an increased deflection, and a consequently erroneous result, so far as the insulating properties of the rubber, paper, bitumen, or other dielectric are concerned.

To eliminate all possibility of error arising out of this same surface leakage, the "guard-wire" principle is adopted. Referring to Fig. 5, a few turns of bare wire are wrapped round the insulation of the conductor under test, at both exposed ends. The wrapping is effected an inch or so away from the exposed metal, as shown at c , d , and the two wrappings connected by an insulated lead to the point e , somewhere between battery B and galvanometer G . On tracing the circuit from the battery to conductor of cable C , and assuming a surface leakage path over the surrounding insulation, it will be seen that all this leakage current is picked up by the guard-wire wrappings, and a return circuit to the battery provided for it, independent of the earth E , and galvanometer G . The leakage current, although passing all the while, will thus leave the galvanometer uninfluenced except by the legitimate testing current actually passing through the insulation.

This simple principle has a large number of useful applications, and is not confined to cable testing pure and simple. Thus, any insulation testing equipment requires to be particularly well insulated in itself if reliable results are to be obtained. All keys, switches, galvanometer, and even the battery, should, properly speaking, be mounted on insulating supports. It often happens, in commercial testing, however, that such desirable conditions are unattainable, and the result is a permanent deflection on the galvanometer before the testing circuit is completed, due, entirely, to surface leakage from the apparatus. Where this

leakage deflection manifests itself it can usually be eliminated by connecting one of the galvanometer

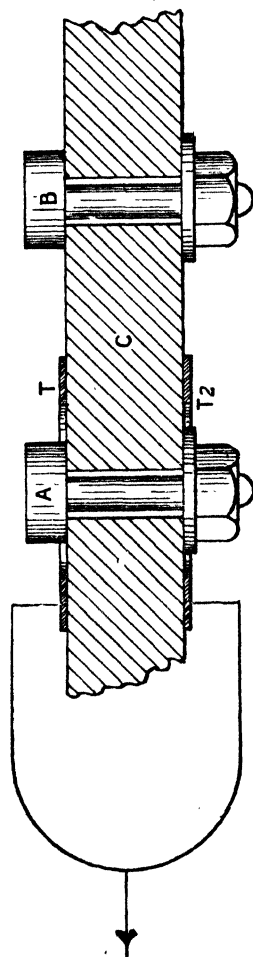


FIG. 6.

terminals to the case or metal frame of that instrument, thus shunting the leak direct to earth, and restoring the needle to zero. The insulation tests can then be carried out as usual, without fear of error.

Another example of the utility of the guard wire, although it hardly comes within the scope of wiring practice, may, nevertheless, prove of service on some occasion when one is faced with an elusive insulation trouble. Thus, in testing the insulation of current-carrying parts or various pieces of plant or apparatus, e.g., a slate switchboard panel, we often require to know the insulation through the mass of the insulation, as opposed to the general insulation which, of course, includes surface leakage. For example, suppose we have reason to doubt the insulation of the slate medium *C*, in which the two contact studs *A*, *B*, are embedded (Fig. 6). We connect *A* and *B* to the testing leads corresponding to *E* and *C* (Fig. 5), and again institute our guard-wire arrangement to shunt out surface leakage. To this end we surround one of the studs, *A*, with two rings or

washers of tin-foil, T , $T2$, pressed into intimate contact with the upper and lower surfaces of the slate by weights, or suitable clamping arrangements. These tin-foil rings surround, but do not actually touch the stud, a clear ring of slate being left all round, top and bottom. The two rings function exactly as the guard wire wrappings in Fig. 5; being connected together, and to the point e , they shunt all surface leakage current back to the battery, in such manner that the galvanometer G remains unaffected, and the second deflection, $D2$, is a true measure of the insulation through the mass of slate separating the two studs.

The same principle may be applied to an infinite variety of insulation tests, and the best method of applying the guard-wire, or ring, will readily suggest itself to the intelligent wireman. Some Meggers are provided with a third terminal for the reception of the guard-wire connexion, and the principle involved is precisely the same in this case.

(10) APPLICATIONS OF THE MIL-AMMETER

Most electrical measuring instruments—ammeters, voltmeters, wattmeters, etc.—lend themselves to a number of rough and ready tests met with in everyday wiring practice, but an efficient mil-ammeter, an instrument which will indicate in thousandths of an ampère, is more useful than any other two instruments used conjointly. The mil-ammeter is usually a moving-coil instrument, having a permanent magnet field, and the best makes are somewhat expensive. A serviceable instrument for rough workshop use, can, however, be purchased for two or three pounds, and, intelligently employed, can be pressed into service on a variety of jobs. It is, however, a very delicate piece of apparatus at best, and, to safeguard it against possible damage by the accidental passage of an excessive current, the Author suggests the arrangement shown in the accompanying diagram,

Fig. 7, which has proved very successful in protecting the shop instruments at a large factory.

The mil-ammeter, M , is mounted on a base board, and one of its terminals connected, as shown, to the main testing terminal (+). A branch connexion is also taken to one winding, a , of a double-wound relay, furnished with an armature contact tongue A , playing between two fixed contact studs. The other

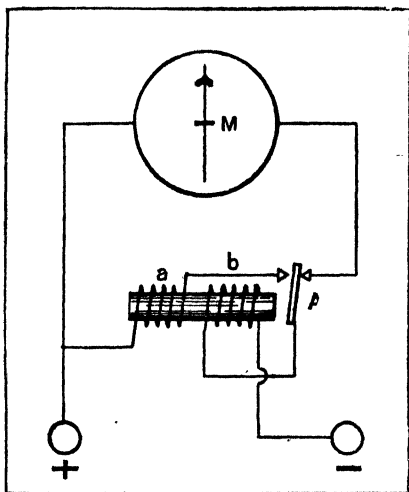


FIG. 7.

end of winding a is connected to the front contact, which is in connexion with the armature tongue when the latter is attracted. A second, exactly similar, winding, b , is connected to the armature tongue, and the other main testing terminal (—). The back contact stud, against which the armature contact tongue normally rests, is wired to the remaining terminal of the instrument. The behaviour of the combination when an excess current passes will be readily followed. The relay is adjusted to work with

one winding, at a current slightly exceeding the maximum range of the scale of the mil-ammeter. If any current in excess of this value pass between terminals + and -, winding *b* energizes the relay, the armature *A* is attracted, and the two windings, thus thrown in series, hold it permanently against the front contact, leaving one terminal of *M* entirely disconnected, whilst the excess current circulates harmlessly through the relay windings. To re-set the combination it is necessary to break the circuit externally, which thus calls attention to the danger.

The resistance of the relay windings *a* and *b* need not be very appreciable; for a mil-ammeter reading up to 500 milliamperes, or .5 ampère maximum, a relay wound to half an ohm either coil, or 1 ohm in all, was found sufficiently responsive to protect the instrument against all risk of injury by excess current.

Now as to the utility of our mil-ammeter combination. First and foremost there is its legitimate duty as a low range ammeter, capable of indicating currents up to, say, .5 ampère (an average maximum range). This enables the current consumption of most carbon and metal filament lamps to be measured directly, and with a degree of accuracy unattainable with an ordinary ammeter. The actual current taken by a domestic annunciator or indicator movement can also be measured, whilst many other direct current measurements falling within the range of the instrument will suggest themselves on occasion.

Being a moving-coil instrument, our mil-ammeter is, in effect, a fairly sensitive d'Arsonval galvanometer, and, as such, is applicable to rough bridge and circuit testing, although the absence of a centre zero is a drawback.

Again, as a leakage indicator it will register the actual leakage current passing to earth from any point in a suspected circuit or installation.

Finally, it can, with a little care and ingenuity, be made to serve either as a direct-reading ammeter or

voltmeter, for the measurement of comparatively high current and potential. For use as a direct-reading ammeter we require a set of calibrated shunts which are connected in series in the main circuit, the mil-ammeter being bridged across their terminals. The current passing through it is then a known fraction of the whole, and, by suitable grading of the shunts employed, the scale readings can be made exact multiples of the actual current passing. Thus, 150 milliampères on the mil-ammeter may represent 15 or 150 ampères, respectively, according as the resistance of the shunt is $\cdot 01$ or $\cdot 001$ of the mil-ammeter winding. Calibration of the shunts is best effected with a standard ammeter in series, and the mil-ammeter connexions made to terminals bolted or brazed in their ultimate position on the shunt. Each shunt should then be stamped with its value for future reference.

For use as a direct-reading voltmeter it is necessary to introduce a resistance in series with the mil-ammeter which, added to the normal resistance of the latter, will aggregate 1,000 ohms. The instrument will then indicate directly in volts.

(11) REPAIRING BROKEN METAL FILAMENTS

The fragility of the earlier pattern of metal filament lamp is well known, and large quantities of otherwise perfect globes have been rendered useless through breakage of the filament, either in transit, subsequent careless handling, or from accidental shock. Most lamp-users will have accumulated a stock of these damaged lamps, and it may interest the wireman to learn how, by the exercise of a little care and ingenuity, a repair can be effected, and the lamp rendered serviceable.

All that is necessary to the operation is a lamp-holder—preferably of the self-contained switch pattern—wired, through a convenient length of twin

flexible, and a cut-out, to a source of current suited to the voltage of the lamps to be repaired. First examine the lamp carefully, holding it up against a light background, such as a window, and note where the filament is broken. Then insert it in the lamp-holder, switch on the current, and endeavour, by careful manipulation of the bulb, to bring the two severed ends into contact. If, as is often the case, the break is at the end of one of the loops where the filament passes over the suspension hooks, care must be taken to prevent the long free end of the filament from falling across two or three of the neighbouring loops, and thus short-circuiting a considerable portion of its length. If once the broken ends can be made to touch whilst current is on, either by lightly shaking or tapping the globe, a momentary arc will be set up between them, and fusion will render the junction complete, when the whole filament will light up as usual.

Repairs executed in this manner will generally last as long as a sound filament, and, even if the junction take place unexpectedly at a point which entails the cutting out of a loop, or portion of its length, the lamp will still be good for a certain "life," in spite of the fact that it is being subjected to an excess of current. Under such circumstances its candle power will be slightly increased at the expense of a shortened life.

(12) RESISTANCES AND ARTIFICIAL LOADS.

There are many occasions when one experiences a need for some convenient form of resistance or artificial load to adjust current values, as in accumulator charging from supply mains, or for dissipating the energy which is being generated by a dynamo under a full load or heating test. The type of resistance available will of course depend on the nature of the work in hand, and the current to be dealt with, but

the following hints may assist the wireman in tiding over a difficulty resulting from lack of conventional material.

For small currents, up to, say, 5 ampères, there is nothing to beat a bank of carbon filament lamps, of suitable voltage, grouped in such manner as to secure the necessary current adjustment. The charging of small accumulator sets from direct current supply mains, through two or more lamps connected in series with the cells, will be familiar to most readers, the lamps absorbing the major portion of the total voltage, and leaving the accumulator a balance of potential across its terminals just sufficient to overcome the back E.M.F. of the battery. Thus, assuming a 4-volt battery connected in series with two 32 C.P. lamps, across a 230-volt supply, we should have approximately 225 volts across the lamps, and the remaining 5 volts available at the terminals of the cells, rising to 6 volts as the charging proceeded. The current can be controlled by varying the number of lamps in circuit, and would amount, in the above example, to approximately 1 ampère.

The same principle of employing carbon filament lamps as resistances, can be applied to a variety of purposes where the available voltage is in excess of that required, or where a fairly high resistance is necessary for testing purposes, and the reader will find it convenient to construct a variable lamp resistance board on the lines indicated in Fig. 8, where *L1*, *L2*, *L3—L8*, represent lamps and lampholders, wired as shown, to groups of metal sockets, *S1*, *S2*, *S3*, etc., so spaced that they can be interconnected by metal U-links in the manner shown by the dotted lines. The arrangement can be conveniently mounted on a square base of teak or other hard wood, using flanged bayonet lampholders. The sockets are made from $\frac{1}{4}$ in. brass bolts and nuts, of suitable length to project through to the rear of the board, where the cross-connexions and wiring to lampholders are

effected, the whole being subsequently covered by a false bottom. A $\frac{1}{8}$ in. diameter hole is drilled to a uniform depth of about $\frac{3}{8}$ in. in the body of each bolt, for the reception of the connecting links, which are made up from $\frac{1}{8}$ in. hard drawn brass rod, bent to a

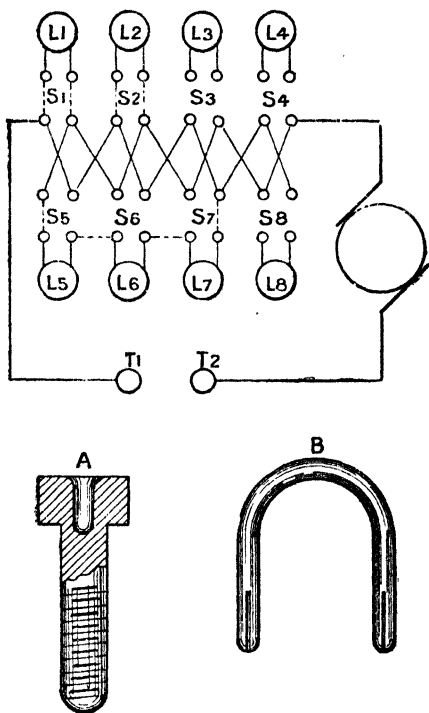


FIG. 8.

U-shape, with the two parallel limbs at centres corresponding with the setting of the studs, and their ends saw-cut to ensure efficient contact.

An enlarged view of one of the studs, and U-links,

is shown at *A* and *B*. *T1* and *T2* are the testing terminals, and a careful study of the internal wiring, and possible U-link inter-connexions will show that any combination of lamps, to the number of eight, either in series, parallel, or series-parallel, is possible, thus providing a wide range of current adjustment under given conditions of voltage and C.P. With the U-links in position as shown, the combination is equivalent to two lamps in parallel, and three in series across the mains, and available as resistance in series with the testing terminals *T1* and *T2*.

Carbon filament lamps of various candle powers can be purchased very cheaply, and, by keeping a fair stock of these lamps alongside the board, its range of adjustment may be considerably extended.

For moderate currents—up to, say, 20 ampères—at comparatively low voltages, the carbon plate form of resistance permits of very fine gradations in adjustment. It comprises a fairly heavy rectangular metal frame, made up of two square or rectangular end-plates, bolted together, some 12 in. or 18 in. apart, by four long steel rods, threaded at their ends, where they pass through the four corners of the plates, and insulated throughout their length by sleeves or tubes of fibre or ebonite, which also serve as distance pieces. The holes for the rods in either one or both plates are bushed with ebonite, and washers of the same material interposed between plate and clamping nuts, thus leaving the two ends electrically insulated from one another. A third metal plate is loosely threaded over the four insulating sleeves, and is free to take up any position, parallel with the end plates as determined by the thrust of a substantial screw, furnished with a cross-bar handle. This screw passes through a tapped hole in the centre of one fixed end plate, whilst terminals are fitted to the remaining end plate, and the third, travelling plate, respectively. Between the two latter are inserted a number of carbon plates, cut to fit the frame transversely (battery carbons will

answer the purpose) which must be fairly flat on both sides, so that, when packed closely together in the frame they make reasonable contact over their two major surfaces. Resistance is adjusted by pressure of the centre screw upon the travelling plate, and the greater the pressure, the lower the resistance.

This form of resistance is fairly inexpensive, and can be readily constructed by any one with a smattering of workshop knowledge, and the necessary materials.

(13) ARTIFICIAL LOADS

for the dissipation of heavier currents, up to 50 ampères, or more, are sometimes required in emergency testing, as, for example, in running a motor off mains of unsuitable voltage, or charging a battery of large storage cells from a machine whose normal voltage is in excess of that required, as, e.g., before the proper charging plant has been installed. For such purposes there is nothing so handy, or easily rigged, as a liquid resistance, and, provided the load be fairly constant, it can be readily constructed from materials generally to hand, or obtainable at short notice.

To make such a liquid resistance, capable of absorbing a current of, say, 50 ampères, procure a wooden tub, or barrel, open at one end (a rain-water butt or wash-tub will answer the purpose). Pour in plain water to some two-thirds of its height, and, for electrodes, take any convenient metal plates, two in number, and not less than a foot square. Drill a $\frac{1}{2}$ in. hole in the centre of one edge of each plate, for the reception of a bolt, nut, and washer, and securely clamp the bared ends of the connecting leads to the two plates. The latter may now be suspended vertically in the water, as far apart as the dimensions of the tub allow, and current switched on. For purposes of adjustment an ammeter, or some means of measuring the current must be included in the circuit.

So long as the water remains pure, no current will flow, and we proceed to render the liquid conductive by adding a small quantity of some convenient acid or salt, preferably the latter. Common washing soda or ordinary salt will answer the purpose, and, to facilitate its diffusion throughout the bulk of liquid, should be first separately dissolved in water in a smaller vessel or jug, thus producing a concentrated solution which can then be poured cautiously into the tub, stirring and watching the ammeter meanwhile, until the desired current is approached within five or ten ampères. A final adjustment can then be made by bringing the two plates nearer together. On no account should the plates be allowed to touch each other, and, since electrolysis is going on all the time current is passing, with consequent evolution of gas and spray, the arrangement should, if possible, be placed out of doors, or at all events, in a position remote from any metal work or apparatus liable to suffer damage.

(14) A SIMPLE TEST FOR POLARITY

There are several well known methods of ascertaining the direction of a continuous current, for the greater part necessitating special apparatus or materials, such as a compass, pole-finding paper, acidulated water, etc., which are not always available or convenient of access. It may therefore interest the wireman to learn that a slip of ordinary blue-print paper, such as is extensively used for the reproduction of engineering tracings makes an admirable pole-finder. The paper is moistened to render it conductive, and the two wires or terminals of the circuit held in contact with it for a few seconds. The deep blue colour in the vicinity of the *negative* pole soon bleaches to a brown or yellowish white, and the effect is obtainable with a voltage as low as that of two or three cells of battery, provided the

paper be sufficiently moist in the first instance to afford a path, for the current.

(15) FUSE HINTS

Generally speaking, a fuse is about the most unsatisfactory link in any electrical installation, on account of its uncertainty of action under given conditions. There are so many controlling factors to be considered in the design of a satisfactory fuse for a given duty, that so far as heavy currents are concerned they have been largely superseded by the electro-magnetically operated circuit-breaker, which, given careful design and construction, can be relied upon to operate under exactly similar conditions every time.

The smallest commercial fuse is rated to blow with a current of 1 ampère, but I very much question whether 50 per cent. of the fuses and cut-outs ordinarily equipped and sold with a simple bridged fuse wire of this rating would give equivalent results within 10 or even 20 per cent., if tested in quantity.

It is possible to procure fuse wire which will melt with .5 ampère, but such wire is in the neighbourhood of 1.5 mils (thousandths of an inch) in diameter, and offers obvious difficulties in the matter of terminal connexion.

Half the small fuse troubles of the present day are attributable to defective terminal connexions. The mass, finish, and design of terminal all have a distinct and important bearing on the behaviour of the fusible medium connected between them, to say nothing of the care exercised in its insertion. I refer more particularly to the ordinary house-service cut-out, or ceiling rose, in which the present day demand for a low-priced article has led to the provision of screws and clamping surfaces peculiarly adapted to the destruction of any fuse wire subjected to their grip. The small metal contact blocks,

unpolished screw heads, and roughly stamped washers, which are features of the average cut-out, require very careful manipulation when inserting a fuse if the latter is to be depended upon in an emergency. All fuse wire, whether of copper, tin, lead, or other metal, should be most carefully inserted under the *washer* of a fuse terminal, and never directly under the screw-head itself. Contrary to the general rule in clamping a wire, the direction of looping should preferably be such that the act of tightening the terminal screw tends to slacken the wire rather than subject it to tension around the stem of the screw. The reverse practice usually results in stretching the fuse, and lowering its melting current, if not fracturing it entirely.

The modern tendency is to employ self-contained cartridge fuses, which, made up on standard lines, and carefully graded to the circuits they are intended to protect, can be relied upon for efficient service, and are, moreover, easily and rapidly replaced when blown.

(16) USES OF VOLTMETER

Failing the necessary apparatus for testing on conventional lines, many useful tests can be performed with the aid of a good voltmeter, the resistance of which should be known, or ascertained beforehand.

To determine the resistance of a voltmeter, connect it with a source of current giving a steady deflection equivalent to about two-thirds the range of its scale. Then introduce resistance in series with the voltmeter until this deflection is exactly halved. The resistance thus introduced will exactly equal that of the voltmeter winding.

(17) MEASURING RESISTANCE

To measure resistance with a voltmeter, connect the instrument as at *V*, Fig. 9, in series with the

lever of a 2-way switch S , and a battery or source of direct current B . R is the resistance to be measured and the remaining connexions should be as indicated in the figure.

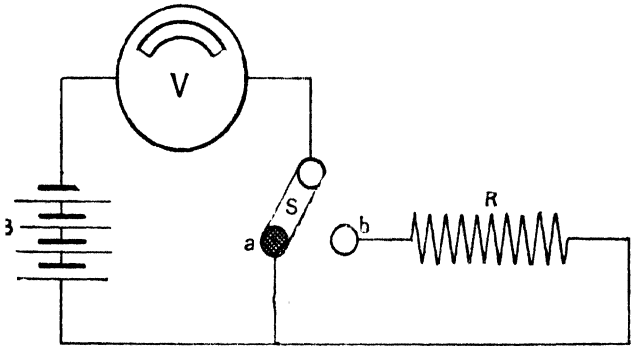


FIG. 9.

Place the switch lever on contact stud a , and note deflection $D1$. Move lever to stud b , and note second deflection, $D2$. Then, if r be the voltmeter

resistance, the required value of $R = \frac{D1 \times r}{D2} - r$.

(18) MEASURING INSULATION RESISTANCE

Provided the source of current be of sufficiently high potential the same method is applicable to the measurement of insulation resistance, and the same formula will apply. Thus, in testing the general insulation to earth of a lighting installation we first connect our voltmeter across the supply mains, obtaining a deflection, $D1$, equal to the normal supply voltage. Leaving one terminal of the instrument still connected to one side of the system, and with all switches on, we then connect the remaining terminal to earth, obtaining our

second deflection, D_2 , which really represents the drop in voltage across the leakage path of the entire system, plus the resistance of our voltmeter. Substituting these values in the above formula, and calculating out, gives the desired insulation resistance in ohms.

In applying this test to a direct current generator, the machine may be made to furnish its own testing current. The open-circuit voltage is first measured by connecting the voltmeter across the brushes (D_1), one terminal of the instrument is then disconnected, and brought into contact with some exposed metal portion of the frame, giving the second reading (D_2).

(19) MEASURING MEDIUM VOLTAGE

To measure a comparatively high voltage with a low-reading voltmeter, connect sufficient lamps in series to glow normally, or slightly below their full C.P. (e.g., five 110-volt lamps on a 500-volt circuit). Connect voltmeter across the terminals of each lamp in turn, carefully noting the several readings, which, added together, will give the total voltage of the circuit.

(20) MEASURING GALVANOMETER RESISTANCE

The resistance of any galvanometer employed for testing purposes is always useful, and sometimes necessary, information, but, as in the case of a simple Wheatstone bridge testing set, for example, there are sometimes difficulties in the way of measuring it directly unless a second instrument be available.

Assuming the usual arrangement of Wheatstone bridge, galvanometer, and battery for resistance testing, the resistance of the galvanometer, G , can be readily ascertained by connecting it, as shown in Fig. 10, to the terminals usually reserved for

the unknown resistance, X . The battery E in this case takes the place of the galvanometer, whilst the usual battery terminals are connected to the

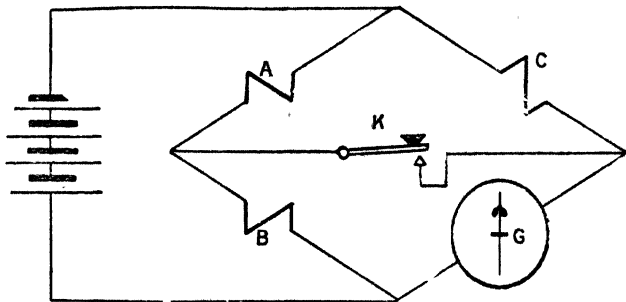


FIG. 10.

short-circuiting key K . The resistance in the variable arm C is then adjusted until the deflection on G remains unchanged whether the key K be open or closed. The required resistance of G will then $= \frac{C \times B}{A}$

(21) MEASURING BATTERY RESISTANCE

A similar bridge test may be applied for ascer-

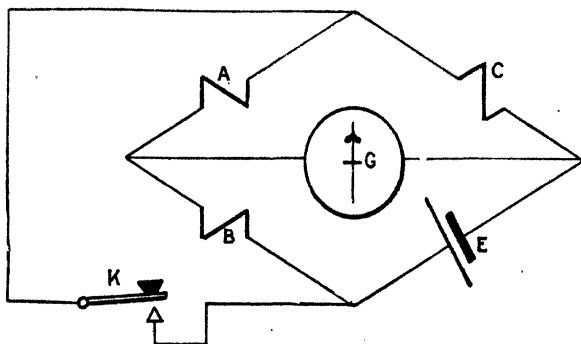


FIG. 11.

taining the internal resistance of a battery, the modified connexions being as shown in Fig. 11. Here the battery under test supplies the necessary current, and, as before, the arm C is adjusted until the same deflection is obtained on G , whether K be open or closed. Similarly, the required resistance of battery $E = \frac{C \times B}{A}$

(22) LOCALIZING SHORT-CIRCUITS

The simplest and most convenient method of localizing a short-circuit fault on a lighting or power installation is to connect a lamp of the correct voltage, in series with one of the main supply leads, at a point where it can readily be seen, or, is at all events accessible from every part of the distributing system. So long as the fault persists, the lamp will glow at full brilliance, and the various sub-circuits can each be disconnected, in turn, until the lamp is extinguished. The particular circuit which, on disconnexion, extinguishes the lamp, is the faulty one, and our test lamp is next transferred to a convenient point on this particular branch, as, e.g., across the terminals of an S.P. fuse on a branch distribution board, the fuse having been temporarily removed. Current is again switched on, and the same procedure adopted until the fault is narrowed down to the single circuit supplying a lamp or fitting, in which, as is most likely, the short-circuit will be found to have developed.

(23) LOCALIZING EARTH FAULTS TO LEAD SHEATH OR METAL CONDUIT

In cases where a conductor is in contact with its outer lead sheath, armouring, or metal conduit, it is possible, provided the current density be sufficient, to localize the fault by measuring the consequent fall of potential along the sheathing or outer

metal conduit. To this end, a sensitive galvanometer or millivoltmeter is connected to any two points, a few yards apart, on the sheathing or conduit, and the direction of deflection of the needle carefully noted. The test is repeated at intervals along the faulty section or its branches, until a position is found at which the direction of current flow in the sheathing is reversed, as indicated by a reverse deflection of the needle. The fault will then lie between this position, and the last one at which the test was applied, and the exact point may be arrived at by carefully repeating the process in shorter stages over the intervening metal.

(24) BELL CIRCUITS

In any electric bell system there are four possible sources of trouble which may be considered separately in fault localization.

- They are :
- (1) The bell.
 - (2) The push-button, or buttons.
 - (3) The battery.
 - (4) Wiring.

The most frequent source of trouble at the bell itself is the vibrating contact, comprising a fixed contact screw, and a second contact carried by a flexible spring attached to and moving with the soft iron armature. In the best quality bells both screw tip and moving contact are of platinum, and seldom give trouble, but the demand for a low-priced article has led to the installation of thousands of electric trembling bells in which the contacts are of base metal, which speedily oxidizes and corrodes, setting up a high resistance at the point of contact with ultimate failure of the bell.

Another frequent cause of failure at this point is the bad fit of the fixed contact screw, a vital point in every trembling bell, since it is subject to constant vibration every time the bell is in action. In

the cheaper bells these screws frequently work loose, and cause irregular or intermittent ringing; or they may even work back in their threads to such an extent as to entirely break contact with the trembler blade. If, therefore, the bell be suspected, careful attention should be paid to these two points, viz., the cleanliness and proper setting of the contacts and the fit of the fixed contact screw.

(25) ADJUSTMENT

As regards adjustment, the best results are obtained when the trembler, hammer and gong are so adjusted that, with the armature held firmly against the poles of the electromagnet, the hammer is not quite touching the gong. The clearance between them should be just sufficient to allow the ball or head of the hammer to strike the gong by springing of its stem when the armature is set in vibration by the current. If the hammer be so adjusted as to touch the gong when the armature is hard over against the magnet poles, the resultant ring will be marred by a mechanical rattle due to the hammer itself damping the free movement or vibration of the gong when struck.

The principle of the adjustment is indicated in Fig. 12, which shows the correct and incorrect settings respectively; *E* being the electromagnet, *C* the contact screw, *G* the gong, and *H* the hammer. It is desirable, also, that the hammer head or ball should strike the gong centrally, and as near its free edge or rim as possible.

Given this preliminary setting of the various parts, the best position of the contact screw *C*, which, in most bells, also regulates the working strength of the trembler spring, is obtained by adjustment whilst the bell is under current and ringing. For greater convenience, it is preferable to take the bell down in order to effect the various

adjustments enumerated above, taking care to use a battery of equivalent strength to that normally employed, since such bells require different adjustments to suit different current strengths.

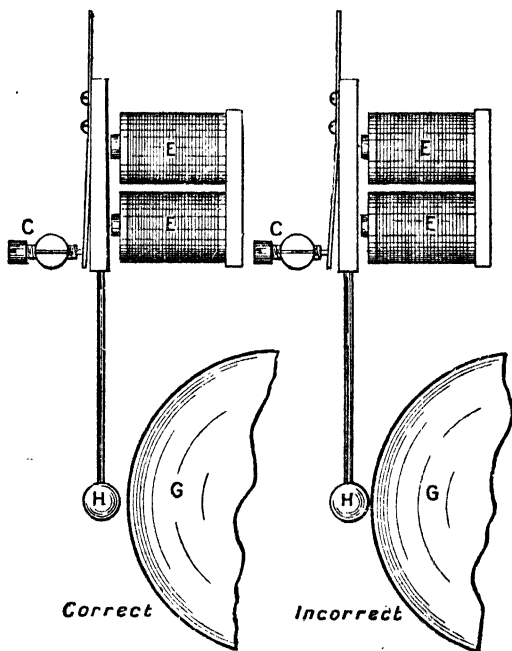


FIG. 12.

Considerable improvement in the action and sound of most electric bells may be effected by careful attention to the foregoing simple rules.

(26) PUSH-BUTTONS

Provided these have been properly installed in the first instance they seldom give trouble, owing

to the fact that the contacts are more or less self-cleaning, and any film of oxide which may form is broken down under pressure upon the button. A common source of trouble where it is found to exist, is the connexion of the wires to the springs, frequently effected with the aid of round-headed wood screws and skimpy washers. Wherever possible, it is better to dispense with this form of connexion, and solder the ends of the wires to their respective contact springs. Care is also necessary to see that the edge of the upper or flexible spring does not foul one of the projecting screw heads, and thus be prevented from touching its companion spring beneath.

In pushes fixed outside, and exposed to the weather, it occasionally happens that moisture obtains an entry and sets up internal corrosion of the springs and wires. This is a common trouble on front-door pushes.

(27) BATTERY

The type of battery almost invariably employed for bell work is the Leclanché, in one or other of its many modified forms. Failure of the battery will generally assert itself gradually, by a decrease in the energy of the ring when the button is pressed, a sure indication that re-charging is called for. In re-charging Leclanché cells it is best to pour away all the old solution, thoroughly wash the glass jars, both inside and out, and scrub the porous pots, or agglomerate blocks. Scrap any zinc rods which show signs of approaching decay. They can be purchased for a few pence apiece, and it does not pay to clean or scrape a zinc which is already half consumed. To prevent "creeping" of the solution, coat the neck of the glass jar, and the upper portion of the porous pot, with paraffin wax. This is best done by inserting them, when thoroughly dry, for the depth of an inch, in a tin of hot melted wax. Any excess of wax remaining on the brass terminal

cap must be subsequently cleaned off to permit efficient contact between wire and terminal. In re-charging use a semi-saturated solution; about 4 ozs. of sal ammoniac to each 3-pint cell. Fill with solution to within about an inch of top lip, or to the level of the wax coating.

(28) WIRING

Faults seldom develop in the wiring of an electric bell system owing to the comparatively low voltage and small current to which the conductors are subjected. Should a fault be traced to the wiring, however, it will in all probability be found at some exposed position where the wires are subject to friction or disturbance, as in cleaning and washing floors and walls, brushing and dusting ceilings, skirting boards, etc.

Another vulnerable point is the helix usually introduced as a flexible hinge when a push is fixed to the door itself, whilst the Author has traced more than one disconnexion to corrosion of the wires near the battery, set up by creeping salts from the latter. Short-circuits, when they occur, may generally be traced to a disregard of first principles in wiring, viz., the securing of two wires under one staple.

(29) TELEPHONE CIRCUITS

Generally speaking, telephone faults are many and various, and call for a good deal of special training and experience before the average wireman can hope to become expert in their diagnosis. If, however, we confine ourselves, in this instance, to the more limited faults common to house and office telephones, such as the wireman is usually expected to cope with, the subject is considerably simplified.

All telephone installations consist of two main parts:

- (1) The calling or signalling equipment.

(2) The speaking circuit and its adjuncts.

Calling is effected either by battery and trembling bell, in which case the same remarks on fault localization apply (see Bell Circuits) or by magneto generator and polarized bell, this being the system generally adopted for lines of any appreciable length.

In magneto telephones the generator is almost invariably fitted with some form of automatic "cut out," which either disconnects or short-circuits the armature when at rest, and re-establishes a connexion with the line directly the handle is turned. Should a fault develop in the calling or ringing circuit it will almost invariably prove to be in this cut-out, and an intelligent study of the internal connexions of the particular instrument implicated will be necessary to a proper solution of the trouble.

It is impossible to describe, in detail, the many different types of cut-out met with in magneto telephones of various makes, suffice it that the majority depend for their action upon a telescopic joint in the main driving spindle, whereby the latter, when the handle is turned, moves axially for a short distance, and in so doing actuates a set of springs, which make or break contact with one another as required.

If trouble be traced to the generator cut-out it will usually be found that the springs are bent or distorted, and have lost their original "set"; that the contacts are dirty and require re-facing; or that the telescopic joint in the spindle is not working freely, either through rust and dirt having accumulated, or the reacting spring having lost its strength. A careful examination of these several parts will usually reveal the fault.

The magneto bell, or ringer, which is actuated by the magneto generator, also calls for careful adjustment to obtain the best and most efficient results. It will be found to consist of an electro-magnet with an oscillating armature pivoted in front of its poles, the pivot screws being carried by a

metal bridge piece, adjustable at either end by means of nuts.

The polarizing permanent magnet should project exactly over the centre of this rocking armature, and the latter be adjusted, by means of the nuts and bridge piece on which it is mounted, such that, when level and parallel with the latter, it is also parallel with both poles of the electro-magnet, and equidistant from them by some $\frac{1}{32}$ in. or less. Under these conditions the hammer stem attached to the armature should be at right angles to it, and the hammer head or ball equidistant from the edges of both gongs, and its ultimate striking point as near the free rims of the gongs as possible.

Assuming these adjustments to have been properly carried out, the armature should remain definitely on either pole of the electro-magnet, thus proving balanced polarization. We next proceed to adjust the gongs themselves, which are either mounted for this purpose on an adjustable pillar, or drilled eccentrically to allow for bringing their inner edges nearer to or further away from the hammer. Holding the armature hard over, first on one pole and then on the other, the gongs should be separately adjusted, in turn, until they just fail to touch the ball of the hammer. When vibrated by the received ringing current the spring or flexibility of the wire stem will then allow the hammer to strike each gong alternately, without damping its natural vibration, and a clear and effective ring will result.

The adjustments having been made to the satisfaction of the operator, all nuts should be finally tightened to ensure permanence, and a trial made of the bell under current.

(30) THE SPEAKING CIRCUIT

In all telephones except those of the "Metaphone" "or parlyphone" pattern (generally installed in

connexion with previously existing bell systems), the speaking circuit comprises a primary or transmitter portion, and a secondary or receiving section. The former includes the transmitter, or part spoken into, the primary or low resistance winding of an induction coil, and the battery; whilst the latter includes the receiver, the high resistance or secondary winding of the induction coil, and the line.

It is obviously impracticable to leave the battery continually in circuit with the transmitter and induction coil primary, or it would very soon become exhausted; whilst it is equally impossible to connect the secondary of the induction coil and receiver permanently to line, or there would be no provision for calling or ringing the station. It is therefore necessary to provide some simple means of changing over the line connexions from the bell to the receiving circuit, and for simultaneously closing the primary, transmitter and battery circuit. These functions are usually performed by the switch-hook upon which the receiver is suspended when out of use, or by the cradle provided for the accommodation of the hand-combination telephone when the latter is fitted in place of a separate receiver and transmitter. In some instruments fitted with hand-combination telephones the primary circuit is closed by pressure of a key in the handle whilst speaking.

Now as to fault localization. If we short-circuit the line terminals of any primary battery telephone, hold the receiver to the ear, and gently blow or speak into the transmitter, the sound should be distinctly audible, and should disappear on depressing the switch-hook or cradle, or on releasing the speaking key if a handset.

Assuming that we get no response in the receiver, the fault may be in either primary or secondary circuits, and may be due to:

- (1) Absence of current; disconnected or exhausted battery

- (2) Defective transmitter ; disconnexion or short-circuit.
- (3) Defective induction coil primary winding (very unusual).
- (4) Defective induction coil secondary winding (equally rare).
- (5) Defective receiver ; disconnexion, short-circuit, or rigid diaphragm due to presence of dust, rust, or iron filings.
- (6) Wiring fault in instrument ; rare, but if existent probably at points of connexion taken through hinges of lid to transmitter and bell mounted thereon.
- (7) Switch-hook or cradle not functioning properly, or contacts dirty.
- (8) Hand-set key not functioning properly or contact dirty.

Investigate these several possibilities in order, and the trouble will soon manifest itself. If the transmitter prove faulty it is advisable to return it to the makers to be overhauled, rather than attempt a repair, as this is highly specialized work, and calls for experienced handling. Most telephone transmitters may very readily be rendered useless by untutored attempts to probe their vitals in search of a defect.

(31) RECEIVERS

are less vulnerable, and such faults usually resolve themselves into a disconnected or broken cord, which should be replaced by a new one ; or by unscrewing the ear-cap the thin iron diaphragm is exposed, and may be carefully removed, and the pole-pieces examined for rust, dirt, or iron filings, which may possibly be damping its free movement. With diaphragm removed, apply a straight-edge to the case, and note if the magnet poles lie well below the rim upon which the edge of the diaphragm

normally rests. If level, a separating ring of paper, some 15 mils thick, should be neatly cut to fit under the diaphragm, and around the edge of the case, thus setting out the former from contact with the poles. Buckled or bent diaphragms never give good results, and should invariably be replaced.

(32) SWITCH-HOOK OR CRADLE

If these be suspected they should be carefully examined and their action noted when the lever or cradle is moved up and down by hand. They comprise a set of two or more springs and contacts, which make or break circuit as the case may be, and it is necessary to see that all such moving contacts are clean, and operating under a fair pressure. Note, also, that the weight of the receiver or handset, when replaced, is sufficient to move the hook or cradle throughout its full range. It occasionally happens, if an odd receiver has been fitted at some time or other, that it fails to efficiently perform this duty by reason of its lighter weight.

(33) EARTH FAULTS

on telephone instruments are frequently found to be at the lightning arrester, which is fitted either on the instrument itself, in the neighbourhood of the line terminals, or on a separate base fixed near by on the wall. Where these arresters consist of opposing serrated metal plates an extremely small gap is left between those plates connected to the terminals of the instrument, and that connected to earth. If mounted directly on wood, it is common for shrinkage to bring these discharge teeth into actual contact, or they may be bridged by accumulations of dirt or dust. In any case, an earth fault should first be looked for at this point.

(34) FLEXIBLE CORDS

The flexible cords which connect the receiver or hand set to the instrument, or the latter to a wall terminal rosette, are also a common source of trouble after having been in use for some time, and disconnections can frequently be traced to these points. Sometimes a cord is intermittent, in which case it can be tested by listening on the instrument in the usual manner, and at the same time moving or shaking the suspected cord, or subjecting it to tension at various points until the fault asserts itself. All faulty cords should be replaced by new ones, and no attempt made at repairing them, as the fact of a cord breaking down in service indicates that it is nearly at the end of its useful life, and temporary repairs to this class of conductor are generally unsatisfactory.

(35) METAPHONES AND PARLYPHONES

These instruments belong to a separate class and faults in them are far simpler to diagnose, since there is no induction coil, the transmitter and receiver being connected in series with the battery and line. They are of the hand-combination pattern, and the receiver is electro-magnetic, i.e., its poles are energized by the current flowing in the circuit, and there are no permanent magnets. The instruments are usually installed in connexion with an ordinary system of bells and push-buttons, and any fault which may arise is generally traceable either to the flexible cord or to the switch-hook contact fitted to bell-push or wall rosette. No attempt should be made to take these hand-sets to pieces as they are delicately constructed, and very susceptible to injury if unduly interfered with.

(36) A USEFUL COMPASS NEEDLE

For distinguishing between the North and South poles of a permanent or electro-magnet, it is usual to employ an ordinary compass, which, held horizontally, and brought near one of the poles of the magnetic field under test, at once indicates whether that pole be North or South, by the well-known law concerning the mutual attraction of unlike poles.

It is not always convenient to use the compass horizontally, as, e.g., in selecting the several poles

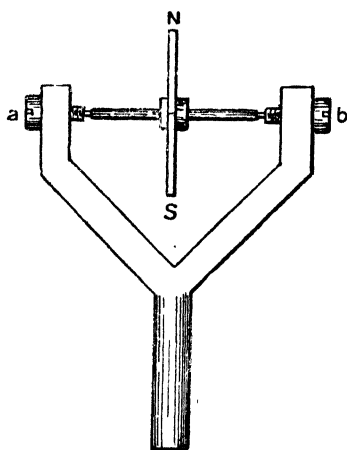


FIG. 13.

inside the armature tunnel of a multi-polar dynamo, whilst, unless the compass be held horizontal, the needle, being only supported on a single pivot, will foul the card or base, and fail to swing freely. Fig. 13 depicts a far more convenient method of pivoting such a needle, for use in any required position, and a well-magnetized needle, thus mounted, will be found extremely useful on a variety of occasions.

The needle, *N.S.*, is of a type used in the construction of "detector" galvanometers, and is mounted as shown, at the centre of a short arbor, delicately pivoted between screws, *a, b*, carried by the two limbs of a brass fork or Y-piece, the third limb of which serves as a handle. The needle should be well balanced as regard its weight on either side of the axis, and the North pole distinctly marked. It will

be seen that this device lends itself to use in any position, and is thus applicable to a number of requirements where an ordinary compass needle would not serve.

(37) LAMPS AND LIGHTING HINTS AND TIPS

(38) INCANDESCENT LAMPS

All lighting installations, more particularly those embodying carbon filament lamps, require periodical inspection of lamps and the renewal of any which show signs of blackening on the interior of the globe. A blackened globe intercepts a large proportion of the light rays from the filament, and is not only an inefficient source of illumination, but also, in advanced stages, tends to overheat, and, if neglected, may prove a source of positive danger to inflammable surroundings.

For similar reasons, the systematic cleaning of the exterior of the globes is desirable, particularly in dusty or dirty situations. Metal filament lamps should always be cleaned with the current on, i.e., with filament glowing.

The fit of lamp-cap and lampholder is also important, many of the continental brands of lamp proving an indifferent match to English lampholders, and vice versa. A lamp-cap should fit its holder snugly and without undue shake or side-play.

Dull burning may occasionally be traced to weak or badly fitting spring contact plungers in the lampholder, or to the metallic connexions between plunger tips and lamp-cap segments having become oxidized or dirty. This is more likely to occur in the case of low-voltage lamps, as used in conjunction with auto-transformers. In soldering the wires leading from the filament to the contact segments on the lamp-cap, an excess of solder is occasionally left on the contact surfaces. This rapidly oxidizes, and forms a path of high resistance between holder and lamp.

(39) NERNST LAMPS

The life of a Nernst lamp glower on direct current circuits is prolonged by maintaining a uniform direction of current flow. If, therefore, a Nernst lamp be removed from its holder at any time, care should be taken to replace it in the same position with regard to the contact plungers; a scratch or mark on lamp cap and holder, prior to removal, will guard against error in replacement.

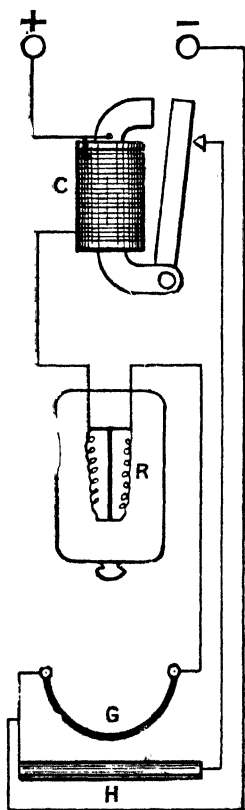


FIG. 14.

The connexions of the usual Nernst lamp, with automatic cut-out, are as shown in Fig. 14, where *C* is the cut-out or relay; *R*, a resistance in series with the glower, *G*; and *H*, the heating coil. The positive (+) lead should connect to the cut-out *C* as shown, and the negative (-) to the common junction of heater and glower.

When a Nernst lamp breaks down the defect usually centres in the heater, which in most lamps is detachably mounted with the glower. These parts can be purchased separately as replacements, and there is no necessity for renewing the entire lamp.

(40) ARC LAMPS

It is impossible to lay down any hard and fast rules

regarding the trimming, cleaning, regulation and adjustment of arc lamps since methods naturally vary with the type and make of lamp, and special rules are usually issued by each maker which should be carefully observed in the handling and maintenance of all lamps of that particular make.

Trimming, the frequency of which depends on the burning hours, should be made the occasion for a thorough inspection and cleaning of such vital working parts as feed rods and carbon holders. The rods are best cleaned and polished with soft cloth or leather, using a trace of paraffin, or, in the case of badly oxidized rods, metal polish. A too liberal and frequent application of the latter is, however, calculated to breed trouble in course of time, and should only be adopted in emergencies.

All contact surfaces, such as those between carbon holders and guides, and between holder and carbon, require to be kept scrupulously clean.

Globes should be wiped out at every trimming with a soft dry cloth, and, if necessary, washed with warm soapy water. Take care to dry thoroughly before replacing.

The fit of the inner globes of enclosed arc lamps is a vital point, and should receive careful attention. The edges of this globe should be ground and fit snugly into the supports provided.

Carbons should invariably be stored in a dry place, or they will absorb moisture, and generate steam when burning, a sure cause of flickering and extinction of the arc.

In direct current open type arc lamps the upper carbon should be cored and the lower solid. After burning for a few minutes the arc should be examined through coloured glasses, and the resistance regulated until the arc is normal. The best guide to correct adjustment is the shape of the lower carbon tip, and not the distance between carbons. In a normal D.C. arc the point of the lower carbon

is well formed. If too long, the point will almost disappear, and a crescent-shaped violet flame rotate around the carbons, causing the light to flicker. Too short an arc is accompanied by excessive length of lower carbon tip. The light is also weak; and the carbons will be in danger of making permanent contact. An improperly regulated arc alters the relative consumption of the two carbons and may thus lead to fusion of one or both carbon holders. Reversal of polarity in a direct current lamp causes the solid carbon to burn twice as quickly as the cored.

In alternating current open type lamps, it is usual for both upper and lower carbons to be cored. Regulation should aim at the longest arc possible, without increasing it to such an extent as to form a crescent flame. In a normal A.C. arc, both carbon points will be well formed horizontally, and there will be no flame. If too long, a crescent-shaped violet flame will rotate around the carbons, and particles of red-hot carbon will be projected from the region of the arc. If too short, an A.C. arc will whistle, and there will be danger of the ends of the carbons sticking together.

For increased illumination use smaller diameter, and for longer burning larger diameter carbons than normal.

A quick test for correct polarity of a D.C. arc lamp is to switch on the lamp for a minute or so, and allow the carbons to heat up. On turning off the current, if the lower carbon stays red longer than the upper, the lamp is burning upside down, and the leads should be reversed.

(41) THE NODON VALVE

When it is necessary to draw direct current from A.C. supply mains, as for charging accumulators, etc., a device frequently employed where the load is comparatively small, is the Nodon electrolytic

valve, or rectifier ; the principle and action of which often prove puzzling to the wireman unacquainted with this class of apparatus. In its usual form the Nodon valve comprises four cells or cylindrical containers, in each of which is a cylinder of lead or iron, surrounding a central rod, composed of an alloy of zinc and aluminium, which is sheathed, for the greater part of its length by a glass tube. The liquid electrolyte with which the cells are filled is a concentrated solution of ammonium phosphate, and the connexions are as shown in Fig. 15, where *Pb* and *Al* represent the lead and aluminium electrodes respectively.

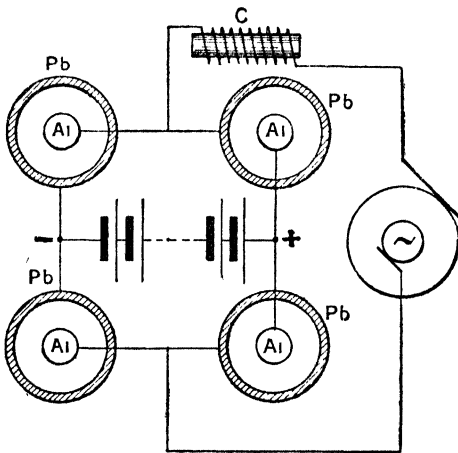


FIG. 15.

The alternating supply is led in, as shown, to the two dis-similar junctions, and the direct current taken off between the similar junctions of lead and aluminium, the (+) pole being at the aluminium junction, and the (-) at the lead. The Nodon valve will work with A.C. voltages ranging from 50 to 140 vol s, and is practically independent of the fre-

quency between 25 ~ and 200 ~ . Its efficiency ranges from 65 per cent at 42 ~ to 75 per cent. at 84 ~ , and the E.M.F. is reduced some ten per cent. in process of transformation. The temperature at which the valve is worked has an important bearing on its behaviour, and, for highest efficiency, should not exceed 30° C., although the valve is still workable up to 50° C.

Where the valve is of small capacity, up to, say, 4 K.W., regulation may be effected by a choking coil *C*, introduced in series with the main A.C. leads. Adjustment may also be effected by insulating sleeves, which pass over the exposed surface of the aluminium rod, and serve to vary the area of metal exposed to the electrolyte. The latter form of adjustment does not affect the efficiency of the apparatus, and is thus preferable in the case of valves of higher capacity.

(42) FINDING RESISTANCE OF WIRE COIL OR BOBBIN BY CALCULATION

It frequently happens that the approximate ohmic resistance of a coil or bobbin of copper wire is required, when no means are immediately available for making an exact measurement. Provided the cubic contents of the winding space can be measured, or calculated, and the wire itself gauged, both bare, and over its insulation, the resistance may be determined with a fair degree of accuracy from the following formula :

$$\text{Ohms} = 960,700 \frac{V}{D^2 d^2}$$

where *V* is the cubic content of the winding space in inches ; *D*, the diameter of the wire over its insulation in mils (thousandths of an inch) ; and *d*, its diameter, bare, in mils.

(43) COPPER WIRE FORMULÆ

Other useful formulæ when dealing with copper wire are as under:—

Weight of bare copper wire, in ozs. =

$$\frac{(\text{diameter in mils})^4 \times \text{resistance in ohms.}}{218,000}$$

Length, in yards =

$$\frac{(\text{diameter in mils})^2 \times \text{resistance in ohms.}}{31.5}$$

Resistance in ohms =

$$\frac{.008 \times \text{length, in feet.}}{\text{cross sectional area in square inches} \times 1,000}$$

Weight, in lbs. = $3.85 \times$ cross sectional area in square inches \times length in feet.

The resistance of copper increases with rise of temperature, .215 per cent. per 1° F.

(44) NOTES ON SPECIAL RESISTANCE WIRES

With a view to securing a negligible temperature coefficient of resistance, coupled with high ohmic resistance per unit of length, several special metals and alloys, of which the more commonly known are German silver and platinoid, have been introduced from time to time for the manufacture of rheostats, resistance boxes, Wheatstone bridges, shunts, and, in short, all classes of electrical apparatus embodying resistance coils which, whilst occupying a minimum of space shall be as little subject to variation with temperature as possible. The average wireman or working electrician frequently has occasion to use, or, at all events, know something of the properties of these special resistance metals and alloys, and the following data is not usually available in the average text-book or electrical pocket-book.

(45) GERMAN SILVER

is an alloy of copper, nickel and zinc, in varying proportions, the resistance of any given sample depending upon its percentage composition and hardness. The German silver of commerce usually contains some 19 per cent. of nickel, but wire is obtainable with a nickel content ranging from 7 per cent. to 30 per cent., hence the variation in commercial samples obtained from different sources. The harder the metal, the higher its resistance. It has a temperature coefficient ranging from $\cdot 00022$ to $\cdot 0007$ per 1° C.

(46) PLATINOID

is an alloy of copper, nickel, zinc and tungsten. It is more stable than German silver, and has a temperature coefficient of $\cdot 00025$ per 1° C.

Constantan—A copper-nickel alloy.

Manganin—A copper-nickel-manganese alloy.

Nickelin—A copper-nickel-zinc alloy.

Vestalin—Not used in sizes below No. 30 S.W.G.

Eureka—A copper-nickel alloy.

Beacon—Will stand temperatures up to 650° C. without injury, and does not become brittle, but should never be used on asbestos. Excellent for rheostat work. Minimum size, No. 30 S.W.G.

Ferno—Practically incorrodible, and therefore suitable for use in damp situations, battery rooms, etc.

The following table gives approximate resistances per mil-foot (i.e., one foot of the wire having a diameter of $\cdot 001$ in.) and the comparative resistance taking copper as unity = 1.

(47)

| Material. | Approximate Resistance per Mil-foot, in ohms. | Comparative Resistance Copper=1. |
|----------------------------|---|----------------------------------|
| German silver ,19% Ni . | 180 | 17 |
| „ „ 28% Ni . | 265 | 26 |
| Platinoid, Martino's . . . | 198 | 23 |
| Constantan | 285 | 28 |
| Manganin | 260 | 25 |
| Nickelin | 260 | 25 |
| Vestalin | 509 | 50 |
| Eureka | 285 | 28 |
| Beacon | 514 | 51 |
| Ferno | 301 | 30 |

(48) CONDENSERS

Although the principle is commonly adapted in telephone and telegraph practice, it is not generally realized by those accustomed to electric light and power circuits that a condenser, whilst arresting the passage of a direct current, will permit an alternating one to flow. In this connexion there are several details, bearing on the construction and behaviour of condensers, which may prove useful in an emergency.

The electrostatic capacity of a condenser depends upon :

- (1) The area of the facing surfaces of its plates.
- (2) The thickness of the dielectric or insulating medium between them.
- (3) The specific inductive capacity of the dielectric.

The following table gives the specific inductive capacities of various materials used in condenser construction.

| Material. | Specific Inductive Capacity. |
|-------------------------------|------------------------------|
| Dry Air | 1.00 |
| Wax | 1.85 |
| Paraffin | 1.92 to 2.47 |
| Ebonite | 2.25 |
| Shellac | 2.74 to 2.95 |
| Glass | 3.1 to 10.00 |
| Mica | 5.0 to 8.00 |
| Rice Paper, paraffined, about | 8.00 |

The capacity of a condenser, in microfarads, can be calculated from the formula :

$$\text{Capacity} = 0.000000225 \frac{A c}{t},$$

where A is the area of one of the two plates, in square inches; c , the specific inductive capacity of the insulating medium, as given in the above table; and t , its thickness, provided the plates are in close contact with it.

A condenser offers an apparent resistance to the flow of an alternating current, depending on the frequency of the current and the capacity of the condenser. This property is known as the "reactance" of the condenser, and may be expressed in ohms. The relation between capacity, frequency, and reactance is expressed by the formula :

$$R = \frac{1}{0.0000062832 f c},$$

where R is the reactance in ohms; f , the frequency, or number of complete cycles per second; and c , the capacity of the condenser in microfarads.

The total capacity of condensers connected in parallel is equivalent to the sum of the individual capacities.

The total capacity of condensers in series is equivalent to the reciprocal of the sum of the reciprocals of the individual capacities.

The facility with which an alternating current finds a passage across the plates of a condenser, is responsible for a peculiar error when a certain type of testing apparatus is employed. At least one firm markets a rough and ready testing set for insulation, comprising a magneto generator and polarized bell, the former being capable of ringing the latter through a certain pre-determined ohmic resistance, say, 100,000 ohms. Broadly speaking, the idea is to connect generator and bell in series with the two poles or terminals of the system whose insulation it is required to test, e.g., an electric wiring installation and earth. The generator handle is then turned, and, if the bell rings, the insulation is regarded as being below the specified minimum of 100,000 ohms, whilst the method has the advantage of subjecting the insulation to the greater disruptive strain of an alternating, as compared with a direct testing current of equivalent voltage.

When employing this method of testing insulation, however, the effect of capacity in the circuit must not be overlooked. Thus, in testing any appreciable length of concentric cable from inner to outer conductor, or, alternatively, a fairly extensive wiring installation to earth, as represented by the protecting conduit, there is a measurable electrostatic capacity present, of which the conductors, on the one hand, and the earth, on the other, are the two opposing plates or electrodes, and it is quite probable that the value of this capacity may be such as to pass sufficient current to ring the polarized bell, although the true ohmic value of the insulation is well above the limiting figure.

(49) MISUSE OF FLEXIBLE CONDUCTORS

The ordinary twin flexible conductor, so largely employed for pendant and portable electrical fittings, electroliers, etc., is a frequent source of breakdown and danger, through misuse and neglect. Flexible

conductors are so convenient a means of connecting almost any electrical fitting or accessory with the nearest fixed point of supply, that they are too often introduced when correct practice would consist in extending the fixed or permanent wiring (be it casing or conduit) and an installation which has been extended and added to from time to time, as necessity arises, frequently includes a considerable length of unnecessary flexible conductor, i.e., in the sense that flexibility between fitting and the point of connexion is not required. This indicates slipshod methods, and a good general rule for the wireman to bear in mind and act upon, is to instal as little flexible as possible on any job ; continuing the permanent fixed conductors to the nearest available position to any pendant or portable fitting.

Every length of flexible should be protected at its point of origin by a D.P. fuse or cut-out. S.P. cut-outs afford little or no protection, since in the event of failure the remaining conductor of the twin is still "live" and the current may find a return path through neighbouring metal.

Breakdowns in flexible conductors are often traceable to the practice of looping up the spare length of conductor around metal standards, gas pipes, window rods, etc., which afford a ready path to earth, and enormously increase the tendency for a fault to develop, particularly on flexible the insulation of which is already weakened by repeated bending and handling.

Another important point in connexion with flexibles is the method of making a terminal connexion. The loose bushy end of the conductor is not in a suitable condition for inserting in a terminal socket, or under a terminal screw and washer. It is preferable to spend a little time and trouble in sweating the loose strands together at the point of attachment, and here, again, care is necessary, for, if too much solder be used, or excess of heat applied, the resultant

“tag” will be too rigid, and the individual wires rendered brittle.

Never subject a flexible to weight or mechanical strain if it can be avoided. It is a common and reprehensible practice, to rely upon the ordinary twin flexible to support the weight of quite heavy pendant fittings, electroliers, etc., and here, it would seem, the makers might borrow a hint from the telephone manufacturer and incorporate a “strain cord,” or idle braid, in all such flexibles, for the purpose of relieving the actual conductors of all save their legitimate duty of conveying current.

A common point of failure is that portion of a twin flexible immediately above the cord-grip in a pendant lampholder. Here the conductors are subjected to maximum bending and handling, the result being aggravated by the fact that they are rigidly held at the point of exit from the lampholder. There is room for improvement in lampholder cord-grips, and the twin-grip holder, in which each conductor is gripped independently, thus halving the wear and tear at this vulnerable point, is a step in the right direction.

(50) LIMITATIONS OF APPARATUS—SOME COMMON ERRORS

Having regard to the facilities now available for obtaining, at nominal expenditure, a very excellent grounding in first principles, it is astonishing how these elementary facts are ignored or misunderstood, even by experienced men, when using standard testing apparatus. Thus, the Author has been witness of more than one attempt to use Wheatstone bridges, test-room rheostats, and similar adjustable resistance units of low current carrying capacity, as regulating resistances for currents amounting to an ampère or more. It is obvious that this class of apparatus is wound for current densities which may be reckoned in milliamperes, rather than ampères,

and a moment's reflection will serve to remind the user of the probable consequences attendant upon such culpable misuse.

Conversely, discrimination is necessary in selecting a suitable rheostat for small current regulation. To cite an extreme case, a rheostat, or adjustable resistance frame normally designed for the control of a 10-amp. arc lamp, would obviously be useless for similarly regulating the shunt field circuit of a small power motor, or other apparatus taking current in the neighbourhood of an ampère. Yet cases almost, if not quite, parallel with the example just given, have come under the notice of the writer on more than one occasion.

Whatever apparatus may be employed upon a test, it is always wiser to investigate its current carrying capacity before subjecting it to use, since a good deal of damage may be condensed into the space of a few seconds by using apparatus which is not up to its work, and the only warning one gets that anything is wrong, is too often a cloud of smoke and an interruption in the circuit, indicating that something has "burnt out."

Another point upon which the amateur electrician is prone to err, is in applying the potentiometer principle to a reduction of voltage in an emergency. He argues in this wise—"If I connect two 110-volt lamps in series across a 220-volt supply, I have a P.D. of 110 volts available between the centre point and either main." Quite correct, so far as it goes; the trouble commences when he attempts to take current from these two points. The moment he does so, the conditions of the circuit are altered, and, instead of obtaining a steady fall of potential equivalent to 110 volts, his terminal E.M.F. will entirely depend upon the resistance of the apparatus connected between these two points. Reference to Fig. 16 will make the matter clear. Here we have two 110-volt lamps, each of 220 ohms resistance,

connected, in series, across 220-volt supply mains, with a current of .5 ampère passing. Between points *A* and *B*, and *A* and *C*, respectively, there is a P.D. of 110 volts. Connect a resistance of, say, 20 ohms across *A* and *C*, however, and the total resistance between these two points becomes 18 ohms approximately, the result being that the lamp between *A* and *B* would burn out. A safe rule, when employing lamps in this manner, is always to use bulbs of the full supply voltage. Then, in the event of one being short-circuited, the remaining lamp will simply

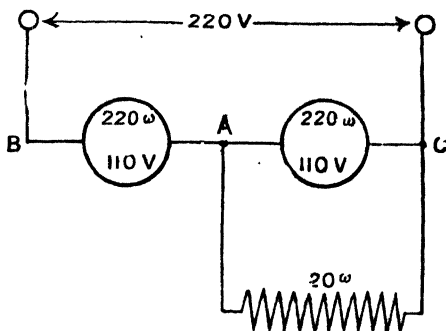


FIG. 16.

burn at full brilliancy, and protect the remainder of the apparatus connected in circuit.

Again, in the case of weak, or exhausted batteries, a common practice is to add one or more fresh cells, in series with the old ones, in order to bring up the terminal voltage to the desired value necessary for ringing a bell, working an indicator, etc. The remedy, if such it can be termed, is worse than the disease, since the additional voltage of the new cells is practically all absorbed in overcoming the internal resistance of the old. A good rule is *never to mix cells* in a battery of any description; either replace

entirely by new cells, or, if fluid batteries be involved, re-charge in the usual way.

(51) TEST FOR DRY CELLS

In this connexion, a good method of gauging the condition of dry cells is to connect them directly across the terminals of an ammeter reading up to about 20 ampères, and note the short-circuit current. This represents the current which the voltage of the cell is capable of forcing through its own internal resistance, plus the negligible resistance of the instrument; and, since the condition of a dry cell largely depends upon its internal resistance, the higher the value of this current, the better the cell. Such a test, on a good cell, should show from 5 to 10 ampères, according to size. As the cells become exhausted, their internal resistance rises; and they show a gradually decreasing short-circuit current. It is hardly necessary to add that this test is unsuitable in the case of accumulators.

(52) THE CARE OF TESTING INSTRUMENTS AND APPARATUS

Too much stress cannot be laid upon the proper care and handling of what are often delicate and costly instruments, such as ammeters, voltmeters, pivot galvanometers, etc., etc. It is seldom that the wireman numbers such pieces of apparatus among his personal possessions, but it nevertheless falls to his lot to handle and use them from time to time, as occasion arises, and their life may be considerably prolonged, to say nothing of their accuracy remaining unimpaired, by judicious and careful treatment.

No instrument, of whatever description, should be subjected to knocks, shocks, or jars, such as may be occasioned by setting it down carelessly on a bench, or leaving it in situations where it is open to the risk of being knocked over or upset. Every mechanical

shock or jar reacts upon the pivots or suspension system, which are necessarily delicate, and susceptible to injury in this manner. The writer has seen some instruments cruelly misused in this respect. Thus, a temporary defect which sometimes develops in the "Megger," is a slipping clutch, the generator handle remaining free, and failing to drive the armature. Your inexperienced wireman finds that a knock or shake will re-engage the clutch, and enable him to use the instrument, so, instead of returning it for overhaul, as he is perfectly entitled to do under the guarantee, he bangs it on each and every occasion that the clutch fails, and one shudders to think of the possible consequences upon the delicately mounted moving system within the case, to say nothing of the deleterious effect upon the permanent magnet constituting the "field."

Before using such apparatus as an ammeter or voltmeter, make sure that the current or voltage you wish to determine is within the capabilities of the instrument. The stops usually fitted at either end of the scale will prevent the needle passing out of sight in the event of an excess current, but do not relieve the delicate moving system of the consequent strain, often resulting in a false zero, or permanently distorted readings. For the same reason, it is desirable always to note the + and - terminals before connecting a D.C. instrument, since a reverse current has an equally bad effect upon the coil or armature.

(53) LEVELLING

Never attempt to use an instrument without first levelling it, if means be provided in the shape of adjustable feet and a spirit level or plumb-bob. These would not have been added if the instrument were not intended for use in a perfectly horizontal plane. Furthermore, do not rely upon levelling screws for extreme adjustments. Place the instrument on a fairly level bench or table, and, if necessary,

pack it to compensate for any perceptible departure from the horizontal, using the levelling screws only for a final and exact adjustment.

(54) ZERO ADJUSTMENT

Some instruments are provided with means for adjusting the needle to zero. This usually takes the form of a screw, normally protected by a small sliding shutter in the case. Such adjustments are only intended to compensate for slight inaccuracies in the position of the needle when at rest, and must never be used for correcting the result of an obvious strain, or the subsequent readings cannot be relied upon for accuracy.

(55) HOT-WIRE INSTRUMENTS

should never be used without a fuse in circuit, rated to blow at the limiting current for which the instrument is designed.

(56) SHUNTS

To extend their range, and enable a single instrument to fulfil a variety of requirements, some ammeters are furnished with a set of shunts, and care is necessary, when using the latter, to ensure good electrical connexion at the terminals provided. A loosely connected shunt, or high resistance set up by dirt or foreign matter at the point of connexion to the instrument proper, will introduce serious errors into the subsequent readings.

In the case of mil-ammeters and low range instruments, the shunts are often self-contained, the instrument being furnished with two scales, one or other of which is used, according to the particular shunt connected. Such shunts are manipulated by a switch, or plug and socket on the base of the instrument, and it sometimes happens that the switch develops play, or its contacts become dirty and worn to such an extent as to affect the value of the

shunt, and, consequently, the accuracy of the readings. A similar result follows when the plug is loosely inserted in its socket, and, in all such instruments it is advisable to watch this point, and check the calibration from time to time, as very serious errors are possible from this cause.

(57) PORTABLE INSTRUMENTS AND LOCKING DEVICES.

Although sold as "portable" instruments, and ostensibly designed for convenient and safe transport, such instruments call for reasonable care in handling if they are to remain uninjured, and retain their accuracy unimpaired for any length of time. It is therefore advisable to handle a so-called "portable" instrument with the same care and respect as you would a similar piece of apparatus designed for switch-board or laboratory use. Portable instruments are often provided with means for locking the moving system, and holding it rigid during transit, and, in such case, it should be manipulated every time the instrument has to be moved. It generally takes the form of a spring catch, or milled screw; in any case a simple device entailing minimum trouble, and the resultant saving in wear and tear, is well worth the small attention needed.

(58) SEALED INSTRUMENTS

Most makers have adopted the practice of sealing the cases of the instruments they manufacture, as a safeguard against tampering by inexperienced and unauthorized persons. There is a temptation, when only slight re-adjustment is apparently required, to ignore these seals, and attempt to remedy the defect without the bother and delay incidental to returning the instrument to the makers for repair. It is, however, far better to respect the seals, and leave it to the makers to overhaul the instrument whenever necessary. They are more experienced, and better

equipped for the work than the average user, and, quite apart from any inconvenience or expense, have their own reputation to uphold, and, given a failure under legitimate usage, will generally repair or re-calibrate their own make of instrument free of charge. An unbroken seal is their only guarantee against fraud in this connexion, and should be respected accordingly.

(59) CURRENT DIRECTION AND POLARITY OF ELECTRO-MAGNET

A golden rule to commit to memory, which furnishes the key to all direct current and polarity problems in connexion with electro-magnets is:— "Swim with the current, facing the core, and the N-seeking pole is on the left." Imagine yourself swimming along the course of the winding, as it were through a tube, with your face next the core of the magnet; then the N-seeking pole of the magnet will be to your left. Assuming the magnetic polarity to be known or determined by means of a compass needle, it is generally possible to trace the run of the winding by inspection of the outer layer, and thus determine the positive pole of the current source. Conversely, the latter being known, it is equally simple, by applying the above rule, to determine the magnetic polarity without the aid of a compass.

(60) TESTING H.P. BY PRONY BRAKE

The principle of the Prony Brake, or absorption dynamometer, as employed for measuring the horse power available at the driving pulley of an electric or other motor, is explained in most text books, but a few notes and the fundamental formula, may prove of service to the wireman, although such tests seldom come his way. The arrangement is shown, as simply as possible, in Fig. 17, where *A* is the motor

pulley; *B*, the brake, comprising two wood blocks, shaped to fit the periphery, and extending across the full width of the pulley face; *C*, a spring-balance; *D*, a lever anchored to some fixed point in the floor, with the spring balance *C*, intervening; and *E*, a counterweight, to balance that of lever and attachments on the spring balance side when the brake blocks *B* are free on the pulley. The direction of rotation is indicated by the arrow.

In making the test the blocks *B* are first adjusted

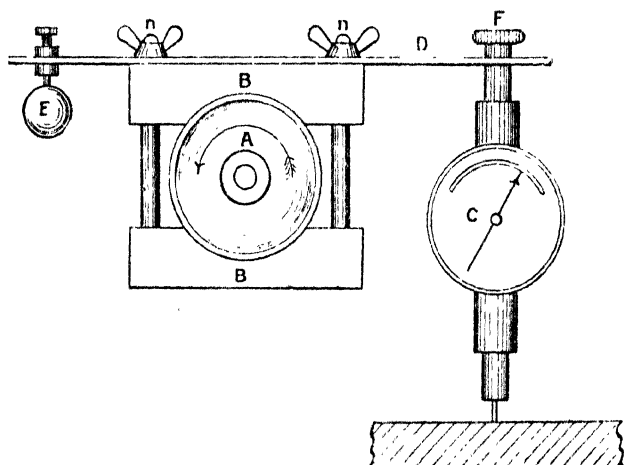


FIG. 17.

to lie slack on the pulley when at rest, the position of counterweight *E*, on the lever *D*, being so adjusted as to exactly balance the latter when horizontal, and the spring balance reading zero. The motor is then started, and run up to its normal working speed, the wing nuts, *n*, *n*, on the brake blocks being adjusted meanwhile, until the speed settles down to a steady value. Simultaneously, the adjustment, *F*, of the spring balance, is manipulated to keep the

lever in its horizontal position. Note the number of revolutions per minute by means of a speed counter, or tachometer, and the pull in lbs. as indicated by the spring balance. Then—

$$\text{H.P.} = \frac{2 \pi r n P}{33,000}$$

where r represents the horizontal distance from centre of balance to centre of pulley, in feet; n , the number of revolutions per minute; and P , the pull, or spring balance reading, in lbs.

(61) OHM'S LAW FOR A.C. CIRCUITS

Ohm's law, as applied to direct current circuits, is too well known to call for mention, but the modified law, as bearing on alternating current calculations, is not so familiar to the majority of electrical workers.

In its simplest form it may be expressed—

$$C = \frac{E}{\sqrt{R^2 + p^2 L^2}}$$

where p stands for $2 \pi n$; n being the frequency; and L , the self-induction of the circuit in henries.

If capacity be present, and no self-induction, the current will *lead* upon the pressure, and—

$$C = \frac{E}{\sqrt{R^2 + \frac{1}{p^2 K}}}$$

where K represents the capacity, in farads.

When resistance, self-induction, and capacity are all present in the circuit—

$$C = \frac{E}{\sqrt{R^2 + \left(pL - \frac{1}{pK}\right)^2}}$$

(62) THE WHEATSTONE BRIDGE; SOME SIMPLE MODIFICATIONS

The fundamental principles, underlying the functions of the Wheatstone bridge, as one of the most useful pieces of electrical apparatus extant, have already been dealt with *ad nauseam*, in almost every book on testing or electrical subjects generally. Some of the explanations are clear; others quite the reverse. I do not propose to deal with the principles of the Wheatstone bridge, further than to contrast it with a simple problem in proportion. Every one is familiar with the ubiquitous lozenge-shaped diagram, one side of which represents X , the resistance to be measured, and across the two pairs of opposite corners of which are connected the battery, or other source of testing current, and the galvanometer, respectively. Balance of potential at the two points leading to the galvanometer, as indicated by the needle remaining at zero, means that the resistances in the four sides of the lozenge are directly proportional, one to another, so that, three of them being known, the fourth may be readily calculated.

By far the simplest form is that commonly known as the "Metre" or "Slide Wire" bridge, in which a stretched wire, of uniform resistance throughout its length, is anchored between two heavy terminal straps of copper or brass, as shown at A , B , Fig. 18. A third heavy strap, of negligible resistance, all but completes the circuit, two gaps being left, as shown. These gaps are respectively bridged by a known resistance R , and the resistance under test, X . Terminals are provided as indicated by the circles, the battery being connected across A and B , and the galvanometer between strap C , and a sliding contact E , in the form of a knife edge, which bears evenly on the stretched wire, with sufficient pressure to ensure a good electrical contact, and carries an index or pointer, indicating its position in relation

to the length of the stretched wire, upon a permanent scale D , of equal divisions, attached to the base board at the rear of the wire.

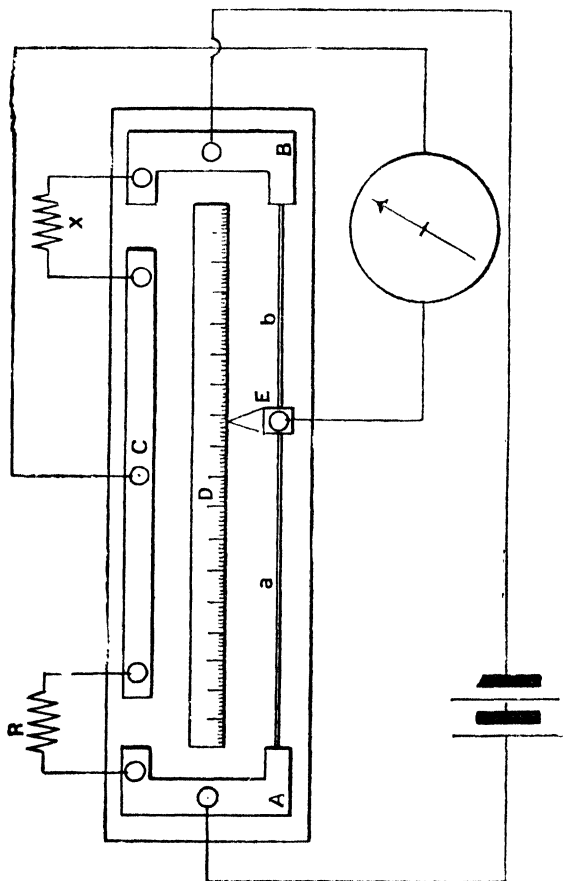


FIG. 18

To use the bridge for ordinary resistance measurements, a bobbin of wire, or any known resistance, of

suitable value, is inserted at R , and the unknown resistance at X . The slider E is then adjusted until the galvanometer needle comes to zero. Assuming a and b to represent the relative lengths of slide wire on either side of E in the positions indicated, then—

$$a : b :: R : X, \text{ or } X = \frac{b R}{a}.$$

The resistance of the slide wire being homogeneous, and proportional to its length, its value in ohms is not required, all calculations being in terms of the relative proportions of the two sections, a and b , on either side of the slider E . These may be millimetres, centimetres, inches, feet, or any arbitrary unit of length, so long as they are uniform throughout the scale. It is this simplicity of detail which renders the "Metre" bridge so convenient. All that it is necessary to know is the resistance R .

Such a bridge is very simple to construct, and entails hardly any outlay. A piece of hardwood serves for the base, whilst the straps, A , B , and C , can be cut from sheet brass or copper, and suitable terminals soldered or riveted in position as shown. Any equally divided scale will suffice; e.g., a three-foot boxwood rule, whilst the slide wire, which must be of the same length, between the edges of straps A and B , as the scale itself, may be of platinoid, say No. 18 or 20, S.W.G. It should be well soldered to the straps, and stretched taut between them.

A little ingenuity will soon provide a suitable sliding contact; thus, an ordinary penny spring tie-clip, modified so as to make contact at a single point only, and fitted with a thin metal or card arrow, indicating on the scale, will answer the purpose. Keys have been omitted in the battery and galvanometer circuits for the sake of clearness, but can take the form of ordinary electric light switches, bell pushes, or any convenient contact making and breaking device.

The standard of comparison, R , may present some

little difficulty to the man who is unable to obtain carefully calibrated coils, since a number of different values are required to give the bridge a useful range, it being desirable to choose a coil for each test which will bring the slider as near the centre of its travel as possible. This means that R should have a value, approximating to that of the unknown resistance, X , although, if it be twice, or even four times X , it is still applicable as a standard resistance. The object in choosing a similar value is to avoid having to calculate on the basis of very short lengths of scale, as would be the case were the slider near either end when a balance is obtained; the possibility of error is thereby lessened.

Failing a proper set of standards, a very fair approximation can be obtained by using any convenient resistance of known value at R . Thus, a voltmeter, the resistance of which is known, or can be found by methods previously described; the shunt coil of a disused arc lamp; the bell coils of a telephone instrument; or its receiver windings, are all possibilities, particularly since the practice of stamping the resistance values of stock coils and windings on electrical apparatus has come into vogue. In any case, a little forethought and ingenuity on the user's part will generally furnish at least a rough standard of comparison, whereby an approximation of the value of X may be attained.

One important advantage which the slide wire bridge has over the ordinary plug pattern is that the slider enables an exact balance to be obtained. Under average conditions this is impossible with the plug pattern of Whetstone bridge, and fractional values involve a calculation based on the relative deflections of the galvanometer to either side of zero, a detail which we need not enlarge upon here.

As intimated earlier in this book, a telephone receiver may be substituted for the galvanometer, and a high frequency or buzzer current for the battery

in the above arrangement, balance, in this case, being denoted by silence in the receiver. Failing a sensitive galvanometer this enables very exact adjustments to be made.

The same principle can be very readily and simply applied to the familiar "loop" methods of fault localization, described in most text-books. A yard or so of platinoid, or even small gauge copper wire, soldered across the ends of the "looped" circuit under test, and the battery and galvanometer connected in the reverse order, so that current actually flows through the fault, will enable an "earth" to be located very exactly. In this case also, the calculation is all in terms of length, and, assuming the conductor to be of the same size, or gauge throughout the loop, is exceedingly simple. If the "loop" include two or more sizes of conductor, however, allowance must be made for the difference in resistance of the various sections in working out the distance of the fault from the testing point.

Thus, assume a "loop" comprising 20 yds. of No. 18 S.W.G.; 49 yds. of 7/18; and 60 yds. of 3/18; bridged by three feet of stretched wire, and with our galvanometer or telephone receiver also shunted across the two ends.

Battery between the slider, or clip, and earth, shows a balance at, say, 12 in. from the testing end of the No. 18 wire. Then the fault will be approximately $15\frac{1}{2}$ yds. from this same point. To obtain this result we reduce the three conductors to a common denomination as regards length. Thus, 49 yds. of 7/18 is equivalent to 7 yds. of 1/18; whilst 60 yds. of 3/18 equals 20 yds. of 1/18; in all, 47 yds. of 1/18 S.W.G.

Then 36 in. of slide wire : 12 in. (the distance at which balance is obtained) :: 47 : 15.6 yds.; the distance of the fault from the end of the 1/18 section of loop.

(63) LAMP HOLDERS AND WALL-SOCKETS ; OVERHEATING TROUBLES

Whilst overheating of any electrical fitting or part of a circuit is usually attributable to overloading, or the passage of a larger current than that for which the particular fitting or circuit was originally designed, there is another cause, less generally recognized, but nevertheless responsible in some cases for apparently inexplicable cases of overheating trouble.

The bayonet pattern of lampholder, for example, relies upon two small brass plungers, backed up by comparatively light spiral springs, making efficient electrical connexion with the terminal plates in the lamp cap. In practice the ends of these plungers are slightly rounded, so that the actual contact is reduced to the proportions of a single point—"without parts and without magnitude"—*vide* Euclid's definition. If, in addition, the lamp contact plates be oxidized, or dirty, or, as is frequently the case, rendered uneven through an excess of solder left by the lamp manufacturer when soldering the leading-out wires in position, there is every prospect of a high resistance being set up at this point, with consequent generation of heat. Thanks to the total enclosure of the contact space by the outer bayonet collar, this heat is retained, and may, in extreme cases, prove a positive danger to surrounding objects. A dull-burning or intermittent lamp is the usual symptom which accompanies this fault, and the lampholder should receive attention first when this defect is noticed, as the trouble is most probably traceable to this point.

Another drawback to the bayonet holder is its convenience and adaptability to the coupling up of such portable and temporary apparatus as fan motors electric irons, and other heating appliances, household vacuum cleaners, etc., all of which take a current in excess of that for which this type of holder is

primarily intended. In the event of regular and consistent lampholder trouble therefore, where fuses are blown oftener than normal circumstances would appear to warrant, and the circuit itself has been proved perfectly in order, it is a good plan for the wireman to look around for, or make judicious inquiries concerning, the uses to which this particular holder is put, apart from its original function as lampholder pure and simple. I add this suggestion because, when a man is called in to replace a fuse, or remedy any trouble of this character, it is usually some hours after the event, and the offending holder may, when he comes to inspect it, have the usual lamp in position, it having been replaced after finishing with the fan or other apparatus originally responsible for the trouble.

Then, again, although frequently regarded as a "cold" light, the average incandescent bulb is capable of radiating a quite considerable amount of heat, and since heat rises in the natural order of things, it is obvious that a lampholder or fitting which supports the lamp in a downward position is far more prone to overheat than an exactly similar fitting in which the lamp stands vertically above its holder. It is well to bear this in mind when investigating overheating troubles.

When used with pendant or downward lamps, a B.C. holder will usually carry up to 2 ampères without trouble, assuming the lamps to be of the ordinary metal filament variety as used for lighting. Radiator, or heat lamps, on the other hand, are designed with a view to maximum heating effect, and minimum luminous radiation; hence the desirability of arranging all radiator lampholders to support their lamps in a vertical position, such that the upward draught of hot air may leave them unaffected except for the heat which reaches them by conduction.

For the reasons above stated it is sometimes urged that wall sockets intended for the connexion of

electric heating apparatus, and other attachments taking up to 10 ampères, should be on the lines of the familiar Edison screw socket, which ensures a larger contact area, together with a positive pressure contact, independent of springs, when screwed home. The principal objection is that the act of screwing and unscrewing the plug entails twisting and untwisting the flexible cord, a treatment which leads to speedy disintegration and breakdown. Common practice is to instal the ordinary two-pin wall plug and socket for connecting all heating apparatus, and small motors, and, in the event of intermittent or imperfect contact at this point, the trouble can usually be remedied by expanding the pins at the longitudinal saw-cut by the insertion of a knife blade, or thin screw-driver.

(64) EARTHING, AND ELECTRICAL CONTINUITY OF CONDUIT, ETC.

The recognized rules regarding the "earthing" of electrical apparatus, conduit, armouring, etc., are fairly well known, but there are one or two points connected with this question which would be the better for a little forethought and revision on the part of those responsible for drafting the official regulations.

Thus, it is obviously insufficient to pay special attention to the detail earthing of various sections of an installation whilst neglecting the primary essential to perfect safety, viz., that the main earth conductor in every instance shall be of sufficiently low resistance and cross section to carry, without overheating or arcing, the maximum current at which the main fuses are rated to blow.

In testing earth connexions it is not sufficient to measure their resistance alone, as current carrying capacity also enters into the question. For this

reason it is better to pass a measured current through the earth connexion, and note the consequent fall of potential between the earthed metal of the system, and the nearest point of connexion to water mains, earth-plate, or other directly earthed conductor. The usual text-book tests involving a bell and battery, or lamps, do not cover this requirement.

(65) A HOME-MADE GALVANOMETER

A fairly sensitive galvanometer, such as is required for bridge testing, fault localization, and so forth, is not always within reach of the average wireman, but an excellent substitute can be constructed by any man of average intelligence and mechanical adeptness, provided he is able to lay hands on a few essential parts.

The d'Arsonval principle of construction, in which a horse-shoe magnet furnishes the field in which a light coil moves, under the influence of the current passing through it, is the easiest to adopt, and the general idea is outlined in Fig. 19, where *M* is a U-shaped permanent magnet, fitted with polar shoes, *N*, *S*., encircling a light rectangular coil of fine wire, *C*. In the centre of this coil, and

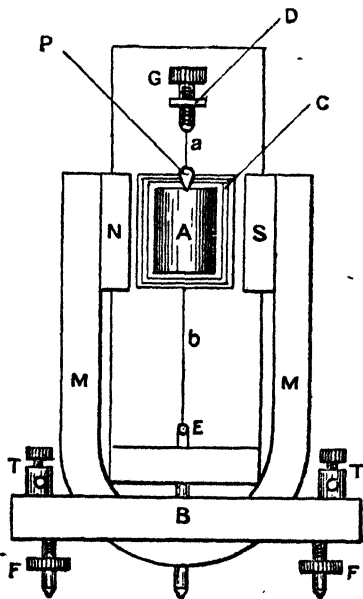


FIG. 19.

partially bridging the gap between the pole shoes, N , S , is a short cylinder of soft iron, A . The whole arrangement is mounted upon a base, B , fitted with three adjustable feet, F , F ; and the coil suspended in position by two thin phosphor-bronze strips, a , b , maintained in tension by a light bow-spring, D . These strips also serve to conduct current into and out of the suspended coil, and, to this end, are soldered to light metal plates, forming the terminals of the coil, top and bottom. The bow-spring, D , and lower anchorage, E , are connected to the terminals, T , of the galvanometer.

As index or needle, a light aluminium pointer, P , or, for greater sensitiveness, a small mirror, may be attached to the upper part of the coil and arranged to indicate either directly upon a curved paper scale, or through the medium of a reflected beam of light as in high class laboratory instruments.

With a little ingenuity, an instrument of this character, sufficiently sensitive and practical for many purposes, may be constructed from the carcass of a disused telephone generator. To this end, the armature is removed, and the box with pole pieces turned at right angles to its normal position, so that the magnets lie parallel with it. Two, or even one, of the original magnets will suffice, assuming them to have retained their magnetism. All that remains is to construct a neat wooden base on the lines indicated, with a slot for the reception of the magnets. Procure a short length of round soft iron for the core, A , and wind, upon a wooden former, a light coil of suitable dimensions to swing freely in the air-gaps left between A and the original pole pieces of the generator.

The best resistance for the coil depends upon the use to which the instrument is to be put, but 100 to 150 ohms is a good all-round figure, calculated to fill most of the ordinary requirements.

The principal difficulty will be experienced in

mounting the coil, and procuring the necessary phosphor-bronze strip for suspension purposes, but most of the leading instrument maker stock this material, and can supply short lengths at a nominal charge. The coil must be swung perfectly clear of both poles and core, *A*, and the ultimate success of the finished galvanometer largely depends upon the accuracy with which this is effected. A mill-headed screw, *G*, mounted in the bow-spring, provides the point of anchorage for the upper suspension strip *a*, and serves as a means for setting the needle to zero and correcting the natural torsion of both strips.

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