 No. 104.

THE INSTITUTION OF
POST OFFICE ELECTRICAL ENGINEERS

CABLE TESTING.

BY

E. S. RITTER, A.M.I.E.E.

A PAPER

Read before the London Centre of the Institution on 17th January, 1923.

(In an earlier form, the Paper was read before the North Midland Centre of the Institution on 25th May, 1922).

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PREFACE.

The paper has for convenience been divided into three parts.

The First Part is intended to be descriptive of the principal operations involved in the laying, jointing, loading and terminating of a main cable, in addition to stating some of the requirements to be met where telephonic repeaters are to be used. Methods of testing are to some extent dependent on the construction methods employed.

The Second Part briefly describes the tests made when accepting completed loading sections of cable from contractors, the tests made when phantom-loading coils are inserted and the tests made when a cable has been completed.

The Third Part treats of faults and of tests for their discovery and localisation: it concludes with some notes on organisation and the records it is desirable to keep.

Since the paper was read certain tables have been added to in the hope that the further information will be of use.

PART I.—CABLE LAYING AND JOINTING.

(1) *Colour Scheme of Multiple Twin Cable.*

The cable usually employed contains a number of pairs of wires covered with paper insulation made up on what is known as the Multiple Twin system (abbreviated hereafter to "M.T.") .

The method of manufacture consists in taking two pairs of twisted wires and further twisting them together to form a two-pair core or quad; furthermore the quads are stranded into layers, the completed core being wrapped with paper and thoroughly dried before being lead covered. The wires of what may be described as "odd" pairs are covered with red or blue paper and of "even" pairs with green or white paper. (In the "old" colour scheme Red pairs were associated with White pairs and Blue with Green; but difficulty was experienced in distinguishing Blue from Green by artificial light and, in the "new" colour scheme recently introduced, Red pairs are associated with Green pairs and Blue with White). One wire of each pair is whipped with red, and the other with white, cotton—the red-whipped wire of a Red or Blue pair is known as the " A " wire of the two-pair core; the white-whipped wire as the " B " wire; the red-whipped wire of a Green or White pair as the " C " wire; and the white-whipped as the " D " wire of the core.* Each core is wrapped with a coloured strip of paper, Orange being used for the marking core, the pairs being Red and White or, in the new colour scheme, Red and Green; simliarly coloured pairs are found in Red and Blue cores. Blue and Green or Blue and White pairs are found in White and Green cores. The rotation of core colours in the old colour scheme follows the order O, W, B, G, R, B, G, &c.; in the new colour scheme, O, B, W, R, B, W, &c., a green core being inserted at the end of a layer to make up, if required, the correct number of cores.

(2) *Balancing.*

After the single lengths of cable have been drawn into the ducts, capacity unbalance tests are made as described in Technical Instruction XIX. The wires and cores of adjacent lengths are jointed, core to core, and pair to pair, in accordance with the results of these tests. This involves, in general, the " crossing " of cores which in different lengths of cable are not adjacent or not, perhaps, even in the same layer, and also the crossing of pairs and wires in each two-pair core.

(3) *Grouping of Two-Pair Cores or Quads in Balancing to secure Separation.*

For four-wire repeater working, owing to the high degree of amplification at Repeater Stations, the " GO " portion of the circuit must have no chance of disturbing the " RETURN " portion: in order to fulfil this requirement the cable cores are divided into groups for balancing purposes and each group is kept distinct, *i.e.*, in the jointing, no two-pair core in a group is joined to a two-pair core in another group. This enables a screening layer to be left between cores which will carry " GO " portions of circuits and those which will carry " RETURN " portions of circuits.

* In some cables the wire cottons are omitted and the " A " and " C " wires are distinguished by a black line on the insulating paper which, in this case, is laid on spirally.

(4) *Effect of Mixing in Balancing on Cross-Talk and Uniformity of Mutual Capacity.*

The balancing fulfils two purposes; it reduces the unbalance between the side circuits or pairs in a core and between the side and superposed circuits and it also reduces the overhearing or cross-talk between circuits in different cores by reducing the length over which any two circuits are adjacent. (Where a balancing group contains a small number of circuits such as the cores forming the centre of a cable there is a liability for cross-talk to build up between these circuits, more particularly the phantoms, as they are always adjacent and are not specially balanced one to another). Another desirable effect of mixing is that whereas different layers and two-pair cores with different lays have, in general, different mutual wire-to-wire and pair-to-pair capacities, mixing in balancing tends to bring these to an average value—a very desirable feature. (See Part II.).

(5) *"Numbering Out" Loading Sections.*

As a result of the balancing, the pairs, as numbered from one end of a loading section, will appear in differently coloured cores and wires at the other end: it is therefore necessary, if the loading coils are to be joined up with any semblance of order, to "number out" pairs from one end of the section to the other; and it is the practice to make a joint at each loading point so that each two-pair core is connected to a two-pair core of a certain definite colour in the stub cable at every loading point along the line. This enables the two-pair cores to be identified at any loading point.

(6) *Crosses inserted at Joints between Groups of Loading Sections in Phantom-Loaded Cables.*

As a result of experiments, it has been found possible to reduce the "phantom to side" cross-talk, if crosses are inserted when jointing groups of three loading coils and sections together; the crosses are made within the two-pair core so that, say, pairs 27 and 28 will always appear in the same core of a loading stub yet the two pairs may be interchanged and the wires of either pair or both pairs may be crossed. It is therefore desirable when opening the cable at an intermediate loading point to use a phantom as a speaker circuit to the jointer who is carrying out the work, *i.e.*, to form the two telephone legs from the two pairs instead of from the wires of one pair; if this is not done the jointer may be on the wrong pair. This point is of importance when opening to localise and clear faults. It is important to identify the particular pair or wire taken before making a test (and neglect to do so recently involved a totally wrong localisation of a breakdown due to moisture in a cable). At the final joint in a cable all the crosses are taken out so that the numbering is correct between the main frames at the ends.

(7) *Jointing Loading Coils.*

As the number of loading coils which it is possible to place in a pot or case without making the pot excessive in size and weight is limited, it is necessary to insert several cases at one point if a large cable is to be fully loaded.

There are three or more possible methods of connecting the cable to two or more cases of coils:—

(1) The American "Balloon" joint which, however, is not used in this country, so far as I am aware. (It is described in the Journal of the Institution of Electrical Engineers, Vol. 60, p. 85, in a paper by Mr. E. S. Byng, M.I.E.E.).

(2) The "solid plug," from which a separate cable is taken to each loading pot installed, any pairs which it is not desired to load immediately being brought out of the main cable in a similar way and either joined through or left disconnected—"stumped"—on each side: from a maintenance point of view it is certainly better to join through as it enables the pairs to be kept under observation; on the other hand more expense is involved in jointing work. As a compromise it is suggested that a few pairs should be joined through when the installation of the future loading cannot be foreseen to be within a reasonable period.

(3) The third method is to construct a "trouser joint" or skeleton plug; this is similar to a solid plug externally but it consists of lead tubes instead of cables. The main cable is stripped

and the cores are made up into their appropriate groups and threaded through the tubes: a joint is thus avoided, but the cable is exposed to damp and moisture during the process and in consequence great care has to be exercised. This method is limited to cases where not more than three or four branches from the main cable are required at any point.

Both methods (2) and (3) have been used on the London-Manchester Cable.

(8) *The Waxing of Joints.*

It is now the practice in certain Districts (and also of some of the Cable Contractors) to boil out the cable with paraffin wax before and after jointing, the time spent in braziering and drying out before plumbing being saved. Other Districts do not wax the joint but wax the testing ends, whilst at least one District does not use wax at all. In my opinion waxing has its good points as well as its bad ones; if it is to be used successfully certain elementary precautions must be taken, otherwise endless trouble will be caused.

Wax immediately the cable is opened.

Wax the lead sheath and work towards the open end.

Have the wax at the correct temperature.

In waxing paper sleeves do not exceed 320°F.

Before closing the joint wax out twice, working from the cable towards the middle of the joint.

When a cable has become wet it is usually preferable not to wax but to rely on a flow of dry air towards the wet place from both sides and the application of local heat; wax may be used for finishing off, but it is liable to trap moisture under the lead sheath.

(9) *The Use of Carbon Dioxide Gas for Desiccating.*

The Author does not at the moment believe in the use of CO_2 for wet cables; but it is excellent for absorbing traces of damp if left in for a reasonable period of time and then let out.

Data on desiccating a wet length of cable furnished by Mr. F. Bird, North Midland District, after the paper was read at Nottingham :—

DESICCATION OF CABLES WITH CO_2.

160 pair 40lb. cables. One 176 yard length. Wet with water at start. 11 cylinders of CO_2 used. (Length tested 1.6 miles).

Aftre days approximate ...				1	2	3		5	6		7	8	9 days.
After Hours ...	0 Ohms		8	14	40	64	112	116	130	154	166	178	202
Insulation of one Quad at Centre to Earth ...	313	700	1330	1700	2440	Megohms 100	175	Inf.					
Insulation of one Quad. Outer layer	277	750	1330	1700	Megohms 300	Inf.	Inf.	Inf.					
Insulation of 40 wires in centre of cable ...									Megohms 100	250	500	1000	Inf.
Insulation of 40 wires in outer layer of cable ...									500	1000	Inf.	Inf.	Inf.

(10) *Terminating Cables.*

Cables have in the past been terminated with beeswaxed silk and cotton cable. It is my opinion, based on experience, that it would be difficult to devise a worse method. S. & C. cable ends have an extremely low insulation, the cotton soaking up moisture, especially if the place is not heated, and a termination of this type will not under bad conditions stand up to a 500 Volt Megger or Wheatstone telegraph circuits. At Fenny Stratford on the Manchester cable a temporary silk and cotton termination of a loading pot had an insulation, wire to earth, of 9 meghoms per wire, though the normal insulation of the cable wire was 400 megohms, *i.e.*, as the cable was over 50 miles long, an insulation of more than 20,000 megohms per mile. The room at Fenny Stratford had a fire in it every day and night and might therefore be considered dry.

The present practice in terminating long cables is to make a pothead with V.I.R. tails. With this method it is important to strip off the tape covering for at least an inch when connecting to the tag on the U-link test tablet. When making the paper-to-V.I.R.-joint and pothead it is necessary to strip the tape between the joint and the middle of the sealing compound.

The author suggests that the proper method is a sealed box filled with compound, the wires terminating on pins mounted on ebonite pillars, similar to the terminating boxes of the London—Birmingham—Liverpool cable, except that instead of filling the box on the site the filling would be done in the factory and an ordinary joint made to the paper cable end. The present U-link tablets could no doubt be adapted to this method by arranging a cover on the back to form a sealing chamber for the cable wires on the centre tags, the outer tags being left for cross-connecting purposes.

The conditions to be met are as follows: —

(1) Easy access to the ends of the cable wires for testing purposes.

(2) High insulation even in a damp atmosphere.

(3) Compactness.

(4) Simplicity and reasonable cost.

It is considered that the present arrangements offer scope for considerable improvement.

In some cases, only a portion of the cable is led into an exchange. The author has frequently noted cases where an odd number of pairs is led in from each direction, thus splitting a two-pair core and rendering that particular two-pair core useless for phantoming, and he suggests that the quad or two-pair core be considered the unit and that only in exceptional circumstances should this be split.

It is sometimes necessary at junction points on a main cable to leave pairs disconnected or stumped. The author considers it a good practice at these points to:—

(*a*) Bring out all spare dead-ended pairs in a stub end of cable, as well as those pairs which will later require rearrangement. This will, in general, obviate the opening in the future of a complicated joint carrying working pairs and consequent interruption of the service.

(*b*) Loop back, quad to quad, the dead-ended pairs. Where there is an odd quad, loop back pair to pair; where there is an odd pair, loop A to B (which should be exceptional). The quads should be looped back so that, say, if pairs 51 to 100 are spare, pairs 51-52 are looped back on pairs 75-76 and pairs 73 and 74 on 97-98 and 99 on 100. This enables the spare pairs to be tested both for insulation and conductor resistance periodically from one end without opening a joint.

Where a large cable is concerned, the leading out should preferably be at a loading point. When this is not the case the point should be prearranged, the loading section being divided into two portions between the leading out and the two loading manholes and each being separately corrected for capacity unbalance.

As regards the numbering of pairs, when spurs are taken out of a main cable, I am of opinion that the numbering on the frame should correspond to the pairs in the main cable and not to those in the spur cable, which would be numbered 29 and 30 North and 29 and 30 South instead of, say 1, 2 and 11, 12. This would enable the pairs to designate a circuit and thus abolish engineering numbers, which lead to endless confusion with the traffic numbers, more especially on repeated circuits, *e.g.*, TSX 25 DY 36 NG would indicate a TSX NG circuit on pair 25 between TSX DY and pair 36 between DY and NG.

(11) *Requirements to be met in cables when telephonic repeaters are to be used.*

In order to use telephonic repeaters (the four-wire method, perhaps, being excepted, at any rate as regards the four-wire portion of the circuit), it is necessary to arrange that the amplified outgoing energy will not react on the incoming energy or the repeaters will howl or sing. This is accomplished by arranging for the outgoing energy to divide either between the line and an artificial network (as in duplex telegraphy) or between the two lines, *i.e.*, the line in and the line out. The first of the two systems is known as the double valve and the latter as the single valve system. Repeater systems will in future be designated by three digits, the first indicating the number of valves, the second the number of ways, *i.e.*, simplex (1) or duplex (2) and the third digit the number of stages of amplification. Thus 2-2-1 is a two valve duplex one stage repeater.

It is necessary so to construct the lines that a balance can be obtained over the range of speech frequencies. To sum it up the lines must be uniform, that is, the capacity unit per length the inductance per loading coil, the spacing of the loading coils and the resistance per unit length must be the same all along the line; the leakance being small does not, in general, count. The two most important quantities are the capacity and the inductance. To secure uniform capacity the cable has to be made carefully (more attention will possibly be directed to this in future); the spacing of the loading coils has to be done carefully to make each loading section as far as possible the same length as the remainder and therefore of the same capacity. With a view to obtaining uniform inductance the manufacturers of loading coils have taken considerable trouble to improve their product, especially as regards the variation of inductance and effective resistance with current and frequency, the result being especially satisfactory in the new "dust core" coils at present being used.

Irregularities in the uniformity of the line cause the impedance, as measured at the repeater station, to vary with the frequency in such a manner as to make it extremely difficult (if not impossible) to construct an artificial network which will imitate the line.

A loaded cable will not transmit frequencies higher than a certain figure, which is governed by the capacity per unit length and the spacing and inductance of the loading coils; on approaching this frequency the irregularities become more pronounced; filters are therefore arranged to cut off the higher frequencies (and, if required, the lower) from the repeaters, so that a balance between the line and network is only required over the range necessary to transmit articulate speech.

At present the limitation in the use of telephonic repeaters is the uniformity of the line.

PART II.—TESTS DURING CONSTRUCTION.

(12) *Acceptance Tests of Loading Sections of Cable.*

The tests which are made when a length of cable between loading coils (commonly known as a loading section) has been joined up will now be described.

They consist of: —

(1) An Insulation Test, which, in addition to proving that the insulation is up to standard, proves that no two wires are in contact.

(2) A Capacity Unbalance Test, to prove that there is no likelihood of any appreciable disturbance between the two pairs in a two-pair core, or between either of the pairs and the phantom superposed on them.

(3) A Resistance Test, to prove that the resistance of the loops is normal and also to prove that the two wires of a pair are of approximately the same resistance.

The above tests are made on all wires in the cable.

(4) A Cross-Talk Test, which is made on a few selected cores to ascertain how far the foregoing requirements have been met.

(13) *The Insulation Test.*

The insulation test is made by taking one wire out of each core and joining it to the corresponding wire in each of the other cores. Each of the four wires in every core is dealt with in the same manner. Four groups are thus formed, each of which is measured in turn to the other three which are joined to the sheath of the cable. A 500 volt high range megger, reading up to 1000 or 2000 megohms, is used for the purpose. The reading, in megohms, multiplied by the number of wires in a group and by the length of the cable, must exceed 10,000, *i.e.*, ten thousand megohms per mile of wire, for the cable to pass as satisfactory.

In addition each four-wire core is taken and measured to the remainder which are joined to the sheath of the cable.

The combination of the two tests proves the absence of contacts or earths. For Megger see Fig. 21, Par. 64.

(14) *The Capacity Unbalance Test.*

The capacity unbalance test, which is made with a capacity bridge and alternating current generated by a reed hummer, is fully described in Technical Instruction XIX.

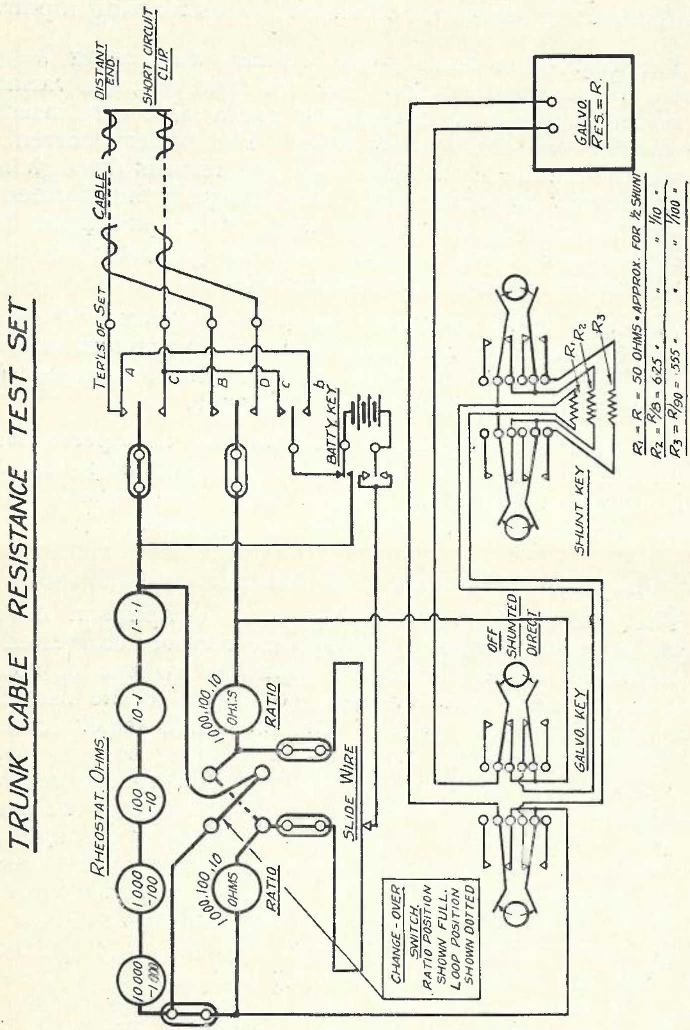


FIG. 1.

(15) *The Resistance Test.*

The resistance test is made with the "Trunk Cable Resistance Test Set." See Fig. 1. The wires for this test are bunched in cores at the far or distant end of the section. (For the first two tests they are insulated.)

The tests made are for the loop resistance of each pair in the two-pair core and also "Ratio" tests to determine the difference in resistance of the two wires forming a pair.

The loop test is made in the ordinary way, using the test set as a Wheatstone bridge. For the ratio test, the variable arm of the bridge is short-circuited and a slide wire inserted between the two equal ratio arms. The battery current is fed into the cursor of the slide wire and returns through one wire of the pair not under test. The bridge is thus formed of four arms consisting of the two wires of the pair under test and the two ratio arms, together with the portion of the slide wire connected to each arm respectively.

The ratio of the resistance between the centre of the slide wire and cursor to the resistance of one ratio arm and half the slide wire is equal to the ratio of the difference between the two wires of the loop to the loop resistance.

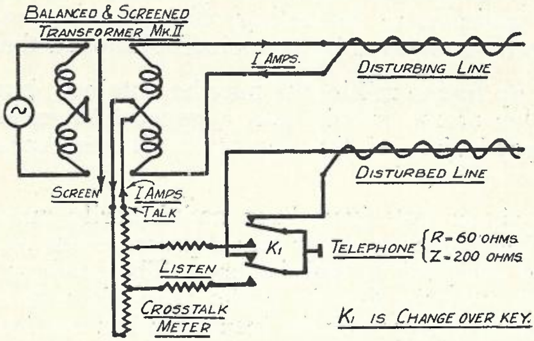
The scale is graduated to read the ratio as a percentage. A ratio above 0.3% may be looked upon with suspicion and as an indication that a dry joint or other defect exists. (For further particulars of the Test Set see Appendix I.).

(16) *The Cross-Talk Test.* See also Par. (49) and (50).

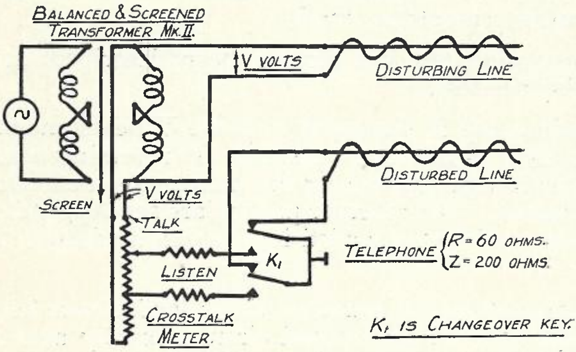
The test consists essentially of a comparison of the volume of sound heard in a telephone receiver connected to the disturbed circuit under test with the volume of sound heard in the same receiver when connected to the listening circuit of a cross-talk meter. The cross-talk meter consists of a resistance through which the disturbing current flows, and a portion of which is shunted by the telephone receiver in series with another resistance. The readings of the meter represent, in millionths of the current passing through the main resistance, the portion of the main current which passes into the telephone receiver. The meter, to be correctly used, should be connected in series with the disturbing circuit, so that the same current flows through both (see Fig. 2); however there are reasons for not doing this and, as at present used, it is placed in parallel with the disturbing circuit, so that the same voltage is impressed on each. The source of the disturbance may be speech from a telephone which, on account of throat fatigue, etc., is usually inconvenient to arrange; a reed hummer or other source of high frequency current is, therefore, generally used.

Tests are made disturbing each of the loops in a two-pair core and also the phantom circuit, the two remaining

MEASUREMENT OF CROSSTALK



"SERIES" METHOD. EQUAL CURRENTS.



"PARALLEL" METHOD. EQUAL VOLTAGES.

FIG. 2.

circuits being listened on in turn whilst disturbing the third.

Another core is also taken and the three circuits are listened on whilst disturbing each of the circuits of the first core, to ascertain if any cross-talk exists between circuits not in the same core.

The tests are made with the distant end (1) open, and (2) closed with repeating coils and resistances which represent, as far as possible, the characteristic impedance of the line. A battery current sent out on one pair and returning on the other pair indicates to the testing officer that the end set has been correctly connected by the jointer stationed there.

Values of up to 250 millionths may be obtained, but this is high: a value of 130 should not in general be exceeded. (For further particulars of the cross-talk set see Appendix III.).

After the above tests have been satisfactorily made (or before), the cable is placed under an air pressure test and the section is then accepted as satisfactory. The loading coils are next jointed in by the District Staffs, who take tests to see that during their jointing work the insulation has not dropped and that other faults have not come on.

(17) *Loading Tests.*

In the case of phantom-loaded cables, tests are made on groups of about three loaded sections after the loading coils have been jointed. Insulation, resistance, inductance and cross-talk measurements are made.

The insulation test has already been described, as also has the resistance test.

The inductance is measured with the Wheatstone bridge at the same time as the loop resistance by reversing a known current in the bridge and noting the momentary deflection on the galvanometer. (For further particulars see Appendix II.) As the phantom circuit is loaded it is tested in addition to the loops.

The cross-talk test is made on every loaded core between the two loops and the superposed circuit, usually also a few tests are made between circuits in different cores.

(18) *The Cross-Talk Switching Test.*

In addition to the above tests, when two adjacent groups of three loading sections have been tested a combined or "Switching Test" is made, a switching set, which will cross the wires of either or both pairs or the pairs themselves, being inserted between the two groups. The combination which reduces the cross-talk between the loops and superposed circuit to a minimum is determined and the instructions for jointing are scheduled accordingly. The switching set consists of three telephone type keys, labelled "AB," "CD" and "PAIRS," one position (the normal) being "STRAIGHT" and the other "CROSSED." The cross-talk values obtained are greater than on single loading sections, values of 300 to 500 or more being met with: an endeavour is made to reduce them to below 250.

The switching test is made from the end of the group nearer the terminal point or repeater station.

As the groups are joined together further tests are made in a similar manner until the cable is completed, all the crosses being taken out at the final joint in order that the numbering between the frames may be "straight."

(19) *Final Tests on Completed Cables.*

On completed cables final tests are made between the frames at the terminal points for Insulation, Resistance, Inductance, Cross-Talk and Speech Transmission. On important cables the cross-talk between each circuit and every other is measured.

(20) *Speech Tests.*

For the speech test, various lengths of circuit are made up by looping back pairs and the speech is compared with that transmitted over an artificial "Standard Cable."

Where possible, the loops are made to correspond to 10, 20, 30 and 40 miles of standard cable. The results are plotted on squared paper as miles of loop against miles of standard cable. In general, a straight line is obtained which for 0 miles of loop cuts the "miles of standard cable" line at a value of from 5 to 7 miles. This last quantity is known as "terminal loss" and varies with the impedance of the line under test.

PART III.—FAULTS IN CABLES AND THEIR LOCALISATION.

(21) *Faults met with when Testing.*

Faults met with may be divided for convenience into two main classes, firstly, those which may be designated "natural faults, such as earths, contacts (including low insulation), disconnections and high resistances in joints and cable lengths; secondly, faults which may properly be described as "jointing errors," such as split pairs, split cores, dry joints, loading coils in the wrong circuits or joined up incorrectly, etc.

(22) *Discovering Nature of Fault before Localising.*

Before proceeding to localise a fault it is necessary to determine its nature; for example, high cross-talk is found to exist between a phantom circuit and one of the pairs on which it is superposed—this might be due to any one or more of the following causes, viz., one wire of the pair in contact or partial contact with earth or another pair, disconnection or partial disconnection of a wire of the pair, faulty loading coil, etc. In some instances the cause of the fault is obvious, such as in the case of low insulation due to wet entering the cable; in others, considerable trouble may be experienced in discovering it. No hard and fast rules can be laid down, especially in a short paper, for discovering the type of fault causing trouble. Experience, initiative, resource and technical skill on the part of the testing officers are the principal requirements. No two faults are precisely the same and it may be necessary to modify the method to suit the fault as faults are not disposed to modify themselves so as to be suitable for any universal method. Frequently the choice of method is limited by the apparatus available—consequently an officer who knows how to adapt his apparatus to his requirements is in a better position than one who does not.

A few of the principal methods of localising certain of the faults generally met with will be given, but it must be distinctly understood that they are not the only possible methods nor are they applicable under all conditions.

(23) *Indications of Faults when Testing.*

Earth and contact faults will be shown up by the insulation test. In the case of a contact, at least two wires will be affected; in the case of an earth fault, on removing the earth connection on the megger but still leaving the remainder of the wires connected to the earth terminal, the fault will apparently disappear, whilst in the case of a contact it will remain. In the case of low insulation, a particular core or cores being low will frequently indicate where the fault should be looked for.

In the case of all faults, the greatest possible care should be taken to see that the conditions at the ends of the cable are in order, but more especially when testing from or to an open end of paper cable.

Disconnections will be shown up by the loop resistance and cross-talk tests, as will also high resistances in the conductor. Split pairs are indicated by the inductance and cross-talk tests; in the case of the latter the "phantom to side" cross-talk will be normal or slightly increased, but the "side to side" will be very high or abnormal.

Split cores will be indicated by high "phantom to phantom" cross-talk on the cores concerned and, if phantom coils are fitted, low inductance will be observed on the phantom circuits involved.

Loading coils joined in circuits which it is not intended should be loaded and left out of circuits which should be loaded are indicated by the inductance and resistance tests.

(24) *The Localisation of Earth and Contact Faults by the Varley and Murray Tests.*

The localisation of earth and contact faults is carried out conveniently by means of the Varley and Murray loop test, the Varley test being the more convenient on long lengths and the Murray on short lengths or where the fault is close to one end. Both tests are described in Technical Instruction IV., which should be studied; they are also given in Appendix VI. to this paper. In both tests, a good wire is joined to the faulty wire at the distant end and measurements made. Where two good wires are available (they need not be of the same gauge as each other nor the same as the faulty wire) both tests may be modified with advantage as follows:—*

Loop the two good wires to the faulty wire at the distant end. See Fig. 3.

Use equal ratio arms in the bridge.

Test (1) The loop resistance of one good wire and the faulty wire is measured, the second good wire being disconnected at the testing end. Let the reading be R_1 ohms.

* The modification to the Murray test is given in Technical Instruction IV. The modification as applied to the Varley test is due to Fisher.

Test (2) The battery is applied to earth or wire in contact as in the Varley test. Let the reading be R_2 ohms.

NOTE:—If the faulty wire has to be joined to the ratio arm of the bridge instead of to the variable arm, R_2 has to be considered a negative quantity.

Test (3) The battery is applied to the second good wire and the resistance to balance, R_3, is obtained. The sign of R_3 is given by the rule referring to R_2.

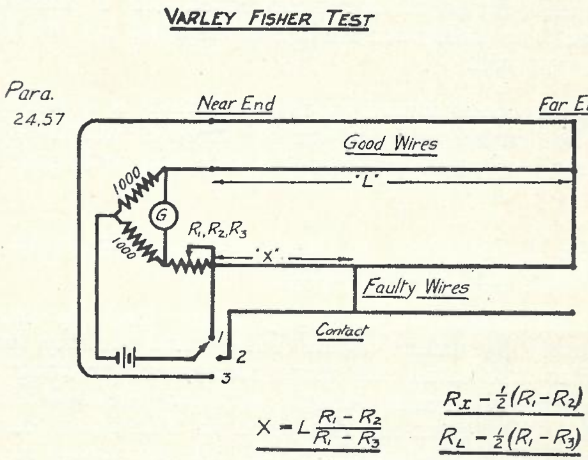


FIG. 3.

Then it can be shown that

(1) the resistance from the measuring end to the fault measured along the faulty wire is $(R_1 - R_2)/2$ ohms;

(2) the resistance from the near end to the far end of the faulty wire is $(R_1 - R_3)/2$ ohms, due regard being paid to the sign of R_3;

(3) the resistance from the distant end to the fault along the faulty wire is $(R_2 - R_3)/2$ ohms, due regard being paid to the signs of R_2 and R_3.

Now it is most desirable that the fault be localised as nearly as possible. Further, it is known that the resistance of a cable changes with temperature. Hence, in a uniform cable wire, it is, in general, more accurate to obtain the fault distance by multiplying the ratio between the resistance to the fault and the resistance to the far end, by the length of the cable. Let X be the distance to the fault and L the distance to the far end.

Then $X = \frac{L(R_1 - R_2)}{(R_1 - R_3)}$ Miles, yards or other units.

and $L - X = \frac{L(R_2 - R_3)}{(R_1 - R_3)}$

Where the good and bad wire are of the same gauge all the way, R_3 will be zero and the above reduces to the ordinary Varley formulæ :—

$$X = \frac{L(R_1 - R_2)}{R_1}$$

and $L - X = \frac{LR_2}{R_1}$

(25) *Method Adopted when Water is Entering a Cable.*

Where the insulation of the cable is dropping rapidly, due to wet entering, it is of importance that the fault should be localised with the utmost rapidity in order to enable a repair gang to start on the job and to prevent, as far as possible, spread of the damage and consequent delay to the restoration of the working circuits affected.

It is first necessary to pick out a good and a bad pair for testing purposes. It is usually possible to find a good pair in the cable; otherwise a good pair in another cable or an aerial loop should be taken. It is invariably better to utilise, where possible, a pair in the faulty cable, as the disturbing effect due to induction from other circuits will be less pronounced in the localising test.

In order to pick out a good pair, run rapidly round the cable, testing in the first instance one wire in each two-pair core or, alternatively, the four wires in parallel. (The latter method may frequently be used from the end of a cable without disturbing the working of telephone loop and phantom circuits where transformers exist). A low range megger is suitable as a measuring instrument. The worst pair should next be picked up, a Detector No. 2 (5 Volt Scale) and, say, a couple of cells being suitable, or, alternatively, the megger may be used in this case also. For accuracy, the ratio of the insulation resistance of the good to the bad wire should be great, say, over 1000, in which case no correction of the result of a Varley loop test will usually be necessary. Measure the insulation A to B of the good and bad pairs, loop the two pairs A to A and B to B at the distant end. With a Detector No. 2, or otherwise, *definitely prove that this has been done.* Trouble in localising due to incorrect looping at the distant end is frequently met with and renders the results of subsequent localising tests valueless.

(26) *Example*

The following results were obtained when localising a wet fault in the London-Manchester Cable :—

Date 28/4/22. Apparatus used: Trunk Cable Resistance test set, including a Paul Unipivot Galvanometer (Pattern " L "); Battery = 20 Dry Cells, Size " X," in the auxiliary Inductance Box; 500-volt Megger.

As no low range megger was available at Fenny Stratford, where the test was made, an insulation test of the faulty pair was made from Leicester.

Distance LE—FBU: 52.8 miles, equal to 33 1.6-mile loading sections—full space each end exactly. (Non-loaded pairs were used).

Pair 105 (good): insulation A to B earthed, and vice versa, over 400 megohms.

Pair 143 faulty: insulation A to B earthed, and vice versa, about 4,000 ohms.

Ratio of the good to bad insulation 100,000, no correction, therefore, being necessary for the Varley test.

105*a* to 143*a*: Loop 2214 ohms; Battery to " B " loop 1207 ohms.

105*b* to 143*b*: Loop 2214 ohms; Battery to " A " loop 1208 ohms.

Wires both 40lb. non-loaded.

Distance to fault

= 52.8 × 1208/2214 = 28.8 miles from the distant end (Leicester),

or 33 × 1208/2214 = 18 loading sections, indicating the fault at loading point 18. (The fault was found at this point.)

The above test was made at 1.0 p.m. when five two-pair cores each had one wire at least above 40 megohms; at 6.0 p.m. only one pair remained with this insulation. Time is therefore of importance. The distance to the fault should be arrived at, where possible, by using the loop resistance measured at the time of making the test rather than using some recorded or calculated figure, as the loop resistance varies with the temperature of the ground.

The following table gives the loop resistance on three previous dates of the wires taken and indicates the error in the localisation which would have arisen had any of them been used in the localisation test :—

Date.	Loop Resistance.	Localisation.	Error which would result.
24/9/21	2287 ohms.	29.8 miles	1.0 mile
8/11/21	2245 ,,	29.2 ,,	0.4 ,,
8/2/22	2188 ,,	28.5 ,,	0.3 ,,
28/4/22	2214 ,,	28.8 ,,	—

Some figures of loop resistance at various dates on the TSX-BM and BM-LV cables are given in Appendix V.

Where, for any reason, it is not possible to make a measurement of the line resistance, the nearest convenient joint should be opened and a further test made at that point or preferably from the ends of the cable to that point, testing officers being in attendance with suitable apparatus for that purpose at both ends of the cable.

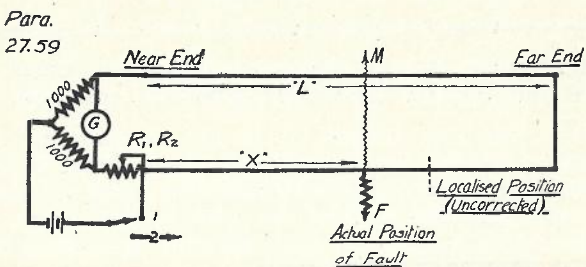
(27) *Test when the Good and Bad Wires have Comparable Insulation. Case* (1), *when the Insulation is Low compared with the Normal Insulation of the Cable and the Low Insulation on Both Wires is at the same point.*

In this case, the normal insulation of the cable is neglected in comparison with the insulation of the fault, and it is assumed that the fault in the good wire is at the same point as the fault in the bad wire. If the fault resistance is above a megohm it will generally be necessary to use a reflecting galvanometer, as it will not be possible to pass through the fault enough current to secure sufficient sensitivity with the " Paul " unipivot galvanometer. In the absence of a high voltage battery a megger forms a useful source of high voltage for the Wheatstone bridge, but it is inclined to make the galvanomeetr difficult to read on long lenghts of cable, as the voltage varies with the speed of turning, the capacity charging currents set up causing the galvanometer readings to vary. This can be overcome by using a megger with a motor drive.

The ordinary Varley test is used but a correction is is applied to the Varley loop reading. Owing to the fault in the good wire, the position of the fault, as localised, will be somewhere between the actual position on the faulty wire and the same position on the good wire going round the loop—that is, it will appear to be nearer the distant end than it really is. See Fig. 4.

Let M and F be the insulation readings of the good and bad wires when measured under the same conditions as when localising. For example, if pair 10 is the faulty loop and pair 20 the good loop, and the test is made as in the previous

VARLEY (CORRECTED)



$$X = \frac{L}{R_1}\left(R_1 - R_2\frac{M+F}{M-F}\right) \qquad R_x = \frac{1}{2}\left(R_1 - R_2\frac{M+F}{M-F}\right)$$

$$(L-X) = \frac{L}{R_1} R_2 \frac{M+F}{M-F} \qquad R_{(l-x)} = \frac{1}{2} R_2 \frac{M+F}{M-F}$$

FIG. 4.

example, then 10A should be measured to 10B and 20B; 20A being connected to the guard terminal of the megger to cut out the direct leakage between 10A and 20A; in the same manner when measuring 20A, 10B should be joined to the guard terminal. After looping 10A to 20A and 10B to 20B the insulation from the A loop to the B loop should be measured and compared with the calculated value MF/(M + F), with which it should agree. As an alternative, the earth may be used instead of the B loop.

The ratio (M + F)/(M − F) is used as a correcting factor or multiplier of the Varley loop reading; when M is great compared with F this factor becomes unity and the ordinary Varley formula is obtained.

It will also be noticed that the error in localisation (expressed as a percentage of the total distance) is a minimum when the fault is at, or very near, the distant end, in which case the Varley reading (R_2) approaches zero.

Let X be the distance to the fault; L the distance to the far end; R_1 the loop resistance; and R_2 the Varley reading. As above let M be the insulation of the good wire and F the insulation of the bad wire.

NOTE:—The good and bad wires must be of the same gauge.

Then it can be shown that:—

$$X = \frac{L}{R_1}\left(R_1 - R_2\frac{(M + F)}{(M - F)}\right) \text{miles, yards or other units.}$$

$$\text{Or } R_x = \tfrac{1}{2}\left(R_1 - R_2\frac{(M + F)}{(M - F)}\right) \text{ ohms.}$$

$$\text{Or } L - X = \frac{L}{R_1} R_2\left(\frac{(M + F)}{(M - F)}\right) \text{miles, yards or other units.}$$

$$\text{Or } R_{(l-x)} = \tfrac{1}{2}R_2\left(\frac{M + F}{M - F}\right) \text{ ohms.}$$

(28) *Example.*

Date: 15/8/21. Cable: TSX—MR. Locality: Fenny Stratford and Little Brickhill. Conductor: 40lb., not loaded. Insulation test to pick out good and bad wires (L.P.33 to L.P.37):

Best core (four wires to earth):	Pairs 141/2:	180,000 ohms.
Worst core do.	do. 109/110:	25,000 ,,

Tested from Fenny Stratford (L.P.33) to opened joint—distance about 2 miles.

Insulation to earth 142*a*: 370,000 ohms = M.
do. do. 109*a*: 70,000 ohms = F.

Hence $\frac{(M + F)}{(M - F)}$ is 440,000/300,000 = 1.47 142*a* looped to 109*a*: Loop Resistance R_1 equal to 89.1 ohms; Varley test R_2 = 1.0 ohm, to an accuracy of 0.1 ohm plus or minus. Source of current: 500 volt megger. Galvanometer: Paul Unipivot (Pattern "L.").

Distance to the fault in yards from the distant end (assuming 40lb. conductor as 22 ohms per mile of wire):

$$L - X = \tfrac{1}{2} R_2 \frac{(M + F)}{(M - F)} \times \frac{1760}{22} \text{ yards} =$$

$$\tfrac{1}{2} \times (1 \pm 0.1) \times 1.47 \times \frac{1760}{22} \text{ yards}$$

= 58.8 yards, with a possible error of plus or minus 5.9 yards.

The fault was found 58 yards from the joint opened and was caused by a split in the sheath of the cable. The duct was dry. Had the correcting factor not been used the localisation would have been 40 yards, plus or minus 4 yards, or an error of about 20 yards.

The following notes will possibly be of use:—

(1) If M = F the fault will localise at the distant end.

(2) Values of the correcting factor (M + F) / (M − F) for various values of M/F.

M/F	= 2	5	10	100	1000
(M + F)/(M − F)	= 3	1.5	1.22	1.02	1.002

The formula used in the above test is not recommended for general use, but it is useful as indicating the probable error in localisation. It was used in the test given above on account of the urgency of obtaining a localisation, as it was considered the cable should have immediate attention in case the ducts should become flooded.

The best test to use is the one covering case (2) and is due to Mr. H. T. Werren, of the Engineer-in-Chief's Research Section, which takes into account the normal insulation of the cable (assumed at its centre point). Case (1) is a particular example of the more general case (2).

(29) *Case* (2). *When the Insulation of the Good and Bad Wires is Comparable with the Normal Insulation of the Cable.*

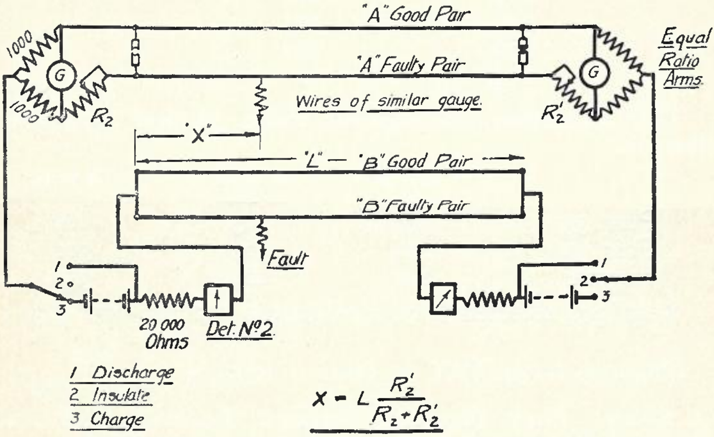
This test is a Varley loop test made from both ends of the cable. It is necessary to use a high voltage battery and a sensitive galvanometer (on account of the small current which it is possible to pass through a high resistance fault). Special precautions are necessary to secure that the testing set is perfectly insulated from earth. Usually the test is made from each end of the cable alternately, and two complete sets of apparatus are required; but sometimes it is possible to loop back on two good pairs and thus bring both ends to the same testing point. In this latter case, only one set will be required. As the capacity charging current is great compared to the leakage current, a long time is taken for a balance to be obtained and the battery is arranged so that it is connected through the fault during the whole time that the tests are being made.

As the results obtainable with this test are dependent on the good normal insulation of the cable, the reason for a high standard of maintenance will be evident. With a

"PRECISION" VARLEY TEST (Werren)

Para.

29.58



$$X = L\frac{R'_2}{R_2+R'_2}$$

FIG. 5.

normal *uniformly distributed* insulation of 300 to 400 megohms it is possible to locate a fault of 600 megohms. If the normal insulation of the whole cable is 30 to 40 megohms there is a possibility of more than one fault existing and thus upsetting the results obtained in the test.

The wires for the test must be of the same gauge and be of similar resistance, *i.e.*, similarly loaded. Equal ratio arms are used.

Let R_2 be the Varley reading from the near end and R'_2 the reading when testing from the distant end, X the distance from the near end to the fault and L the length of the cable.

Then $X = L\dfrac{(R_2 + R'_2)}{R'_2}$ miles, yards or other units.

(30) *Example.*

Date: April, 1922. Cable: TSX—BM. Length: 109.5 miles. Pairs 33 and 36 looped A to A and B to B and the Varley test made to B loop. Both pairs loaded with side and phantom coils. Conductors: 100 lbs.

Resistance to balance in Varley test when testing from:

TSX.	BM.
291 ohms.	103 ohms.
287 ,,	103 ,,
285 ,,	103 ,,
283 ,,	102 ,,
280 ,,	103 ,,
276 ,,	102 ,,
274 ,,	

The insulation readings of Pairs 33 and 36 were as follows:—

	A to B earthed.	B to A earthed.	A to B.
Pair 33 ...	90	95	180
Pair 36 ...	150	160	300
Normal ...	200	200	350

Readings selected from localisation test 280 and 103.

Distance from TSX to fault $= 109.5 \times \left(\dfrac{103}{103 + 280}\right) =$ 29.5 miles. Fault therefore between Markyate L.P., 28.5 miles, and Kensworth L.P., 30.96 miles from TSX.

Notes on the above example:—

The figure obtained of 280 and 103 will, if the ordinary Varley formula be used, give limits between which the fault must lie (assuming only one fault to exist).

Thus in the example above, with a loop resistance of 1015 ohms for the 109½ miles the fault is between 11.1 miles from London and 30.2 miles from Birmingham, leaving a gap of 68.2 miles. The length of the gap will vary with the difference between $(R_2 + R'_2)$ and the loop resistance; when $(R_2 + R'_2)$ equals the loop resistance R_1, the normal Varley formula applies. It will also be seen from this example that the formula given in Section 27 cannot be used as ratio of $\frac{M}{F}$ of $\frac{300}{180}$ (which includes the normal insulation) gives a correcting factor of 4, which would place the fault beyond the end of the cable : $X = \frac{109.5}{1015}\left(280 \times \frac{480}{120}\right) = 121$ miles—an obviously incorrect result.

(31) *The Murray Loop Test.*

To carry out this test for the location of a contact or earth fault, the faulty wire is looped to a good wire at the distant end, the loop forming two arms of the bridge and the measuring bridge consisting of two resistances of which one at least must be variable. One side of the battery or source of current is connected to the juncture of these two resistances, and the other side to earth or the wire in contact with the faulty wire. The galvanometer is connected across the juncture of the ends of the loop and the two resistances.

The Murray test is generally used on short or very low resistance loops and also when it is required to determine accurately the position of an earth or contact close to the testing end of the cable. (A modification is also applicable when the contact is close to the distant end).

The following modification of the test (due to Mr. L. J. Sell : *Journal of I.P.O.E.E.*, Vol. XI., p. 225) will be found useful where the two resistances forming the bridge are both adjustable. In locating on a short loop, set the two resistances so that their sum is twice the length of the cable in any convenient unit of measurement. Obtain a balance by cutting out resistance in one rheostat and inserting it in the other. When balanced, the distance to the fault, in the units of distance chosen, is numerically equal to the reading in ohms of the smaller rheostat.

(32) *Modified Murray Test to Locate with great Accuracy a Contact near the Testing End.*

It is sometimes necessary to locate, as accurately as possible, a contact in a length of cable in order to avoid, for instance, opening a long length of the sheath. The principal error in a test of this nature is due to the resistance of the testing leads : this may almost be eliminated by connecting the galvanometer by means of separate leads across the cable ends, thus making the leads part of the bridge. For example, the leads may have a resistance of 0.1 ohm, equivalent to four yards of 20 lb. conductor or 20 yards of 100 lb. conductor. If the smaller arm of the bridge is 10 ohms, adding one lead will make it 10.05 ohms, or an error of 1 in 400, which, in general, may be neglected; on the other hand, a resistance of 0.05 ohm on the end of a 100 lb. conductor will cause an error of 10 yards.

(33) *Example.*

A wire in a cable length was in contact with the sheath and removal of the fault involved breaking into the duct line and opening the sheath of the cable. The cable was 3360 yards long and the loop resistance of 6720 yards of conductor of 70 lb. gauge was 45.81 ohms, equal to 0.0683 ohm per yard. The Murray test ratio—10/1730—gave a distance to the fault of $10 \times \frac{6720}{1730 + 10}$, equal to 38.6 yards.

The fault was actually found 39 yards 7 ins. = 39.2 yards, away—an error of 0.6 yard or 1.5%.

Using the galvanometer on the bridge in the ordinary way and neglecting the resistance of the leads the ratio found was 7/1000, giving a distance of 46.7 yards, a difference of 7.5 yards: if allowance be made for the resistance of the lead (0.06 ohm), equivalent to 8.5 yards of conductor, this gives a nett location of 37.9 yards, an error in the other direction of 1.3 yards or 3.3%.

In locating a contact in a loading coil case the method is useful to determine whether the fault is in the case or only at the bottom of the stub cable.

(34) *The Murray Test for Locating Faults with High Insulation.*

Mr. H. T. Werren has devised a method of locating high insulation faults using the Murray test. The apparatus consists of 1000-ohm slide wire, sensitive reflecting galvanometer and high voltage battery, all in duplicate as the test is made from both ends of the section. The test may be made to earth, as, in a short length, less trouble is experienced from varying earth potentials and capacity charging currents. The wires must be of the same gauge. See Fig. 6.

Let P/Q be the ratio, testing at the near end, and P'/Q' the ratio when testing from the far end, $(P + Q)$ being equal to $(P' + Q')$ and to 1000 ohms. Let, as before, X be the distance to the fault and L the length of the cable. Then

$$X = L \frac{(P - Q) + (P' - Q')}{(P' - Q')} \text{ miles, yards or other units.}$$

(35) *Example.*

This test is a continuation of the localisation given in Section (30).

Cable: TSX—BM. Locality: Markyate and Kensworth.

Apparatus used:—1000-ohm slide wire, reflecting galvanometer, high voltage battery, keys, etc., all in duplicate.

"PRECISION" MURRAY TEST (Werren)

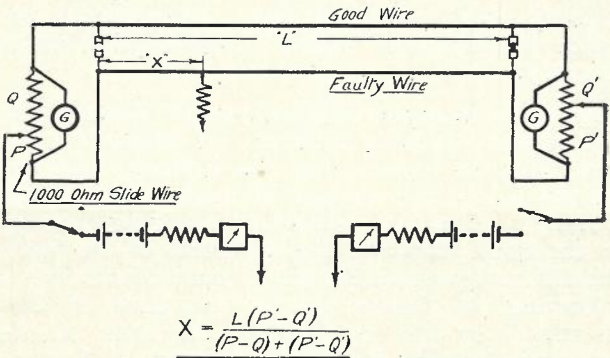


FIG. 6.

The test was made to earth, using the A wire of pair 33 and the A wire of pair 36.

Insulation to earth of wires used 33*a* = 150 megohms.
do. do. 36*a* = 350 ,,

Length of section: 2.5 miles.

Readings obtained in test (in ohms from the end of the slide wire connected to the faulty wire):

P	P′	P – Q	P′ – Q′
443	369	114	262
448	371	104	258
451	376	98	248
451	377	98	246
451		98	

From the mean of the last two tests

$$X = 2.5 \frac{247}{247 + 98} = 1.785 \text{ miles.}$$

The joint at 1.8 miles was opened and the fault found. The cause of the fault was a porous wipe.

(36) *The Localisation of Disconnection Faults.*

Disconnection faults on short lengths of cable may be localised by the method given in Technical Instruction IV., Paragraph 102, using a slide wire, reed hummer, screened transformer and telephone.

On long lengths of cable this method cannot be used on account of the impedance not being strictly inversely proportional to the capacity. As an alternative, the telephone and buzzer may be replaced by a reflecting galvanometer and a battery with a reversing key. Adjustments are made on the slide wire until no "throw" is perceptible on reversal of the battery.

Where there is appreciable leakage the galvanometer will give a false zero, causing difficulty in obtaining a balance when reversing the battery, but this difficulty may be overcome by the use of the mixture method, which is preferred by the author. The test consists of charging the capacities between the good loop and the two parts of the faulty loop from two different potentials, one, at least, of which is adjustable; allowing the charges on the two parts of the faulty loop to cancel or mix by joining the ends of the loop together; and allowing the residual charge to flow through the galvanometer by joining it between the two loops. The potentials are adjusted until no residual charge is left, in which case the charges will be equal. Since the charge or quantity of electricity in a condenser is equal to the capacity multiplied by the potential, it follows that the capacities of the two portions of the faulty loop to the good loop are inversely proportional to the potentials impressed across them.

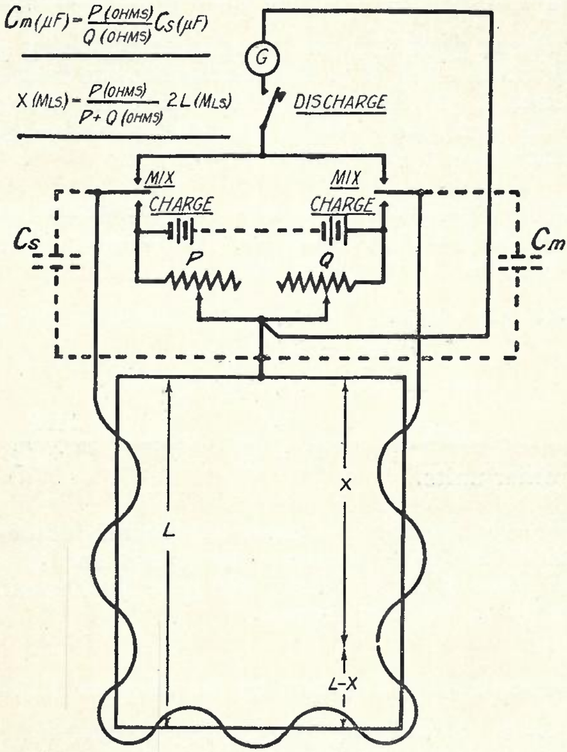
The test is carried out as follows (see Fig. 7):—

Apparatus required: Sensitive galvanometer and shunt, battery, two resistances (Rheostats, F) or a slide wire of not less than 1000 ohms, and a special key. (The special key might in an emergency be made up of a "Key 28A" or some type of Double Current Telegraph key—this is only suggested as a last resource on account of leakage troubles).

The battery is connected across the two resistances in series; the junction point of the resistances is connected to the good loop and one terminal of the galvanometer; and the

DISCONNECTION OR CAPACITY TEST

METHOD OF MIXTURES



NOTE: THE DOTTED LINES INDICATE THE CONNECTIONS FOR MEASURING THE CAPACITY OF A CONDENSER.
C_S = STANDARD CONDENSER.
C_m - CONDENSER UNDER TEST.

FIG. 7.

ends of the faulty loop are connected to the two moveable contacts of the key. Depression of the key connects the faulty loop across the battery, time is allowed for the capacities to charge; the key is raised, joining the two ends of the faulty loop together; time is allowed for the charges to mix before connecting the galvanometer to the juncture of the ends of the faulty loop (the other side of the galvanometer being already connected to the good loop). The resistances are adjusted until no residual charge is shown by the galvanometer, after carrying out the test as outlined above, when, as the same current flows through both resistances, the voltage across each is proportional to its reading in ohms.

Let P and Q be the two resistances (Q being joined to the faulty wire). Let X be the distance to the fault from the testing end, L the distance to the far end. (NOTE.—The wires of the faulty pair are connected to a similar good pair at the distant end A to A and B to B).

Then P × capacity of the wire, *via* the distant end to the fault to the good loop, is equal to Q × capacity of the faulty wire, to the fault, to the good loop.

Hence, the capacity being proportional to the distance,

$$P(2L - X) = QX$$

$$\text{or } X/(2L - X) = P/Q$$

$$\text{or } X/L = \frac{2P}{(P + Q)} \quad \text{or } X = \frac{2LP}{P + Q} \quad \text{miles,}$$

yards or other units.

If (P + Q), in ohms, is made numerically equal to twice the length of the cable in some convenient unit of measurement, the value of P, in ohms, will give the distance of the fault directly in the unit chosen.

(37) *Measurement of Capacity by the Mixture Method.*

The same method may also be used to measure capacity, a standard condenser being connected in place of the good wire, and the capacity to be measured in place of the bad wire. Let Cs and Cm be the standard capacity and the capacity to be measured, respectively: then

$$Cm = CsP/Q$$

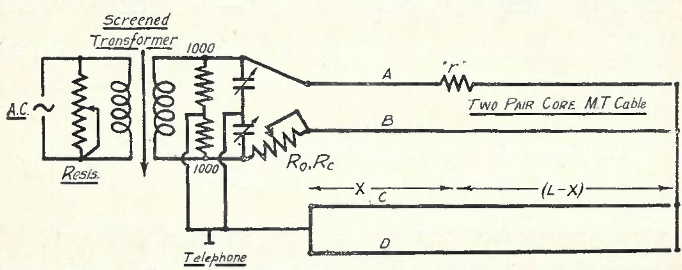
In this case, it is convenient to make Q a multiple of the standard capacity in microfarads, P then becoming the same multiple of the capacity to be measured. For example, if Cs is one microfarad and Q 1000 ohms, Cm is equal to P/1000 microfarads.

(38) *A Test for Locating a High Resistance in a Conductor in a Short Unloaded Length of Cable.*

This test is made with alternating current from a reed hummer, using a telephone, ratio arms, air condensers, screened transformer, and a resistance indicating tenths of an ohm. In addition, a rheostat for adjusting the testing current is necessary. See Fig. 8.

The apparatus is connected up as mentioned in Appendix VI., the rheostat being in series with the good wire of the faulty pair. A core of M.T. cable is tested alternately with the distant and shorted and disconnected and a balance obtained on the rheostat. In the closed test, it is important

HIGH RESISTANCE. SHORT UNLOADED LENGTH (Ritter)



R_0 END OPEN $\qquad$ R_c END SHORTED

$(L-X) = L\sqrt{R_0/R_c}$ $\qquad$ $X = L(1-\sqrt{R_0/R_c})$

FIG. 8.

that the current be reduced to a minimum. In the open test, it is necessary to balance up the residual capacity on the air condenser to secure greater accuracy in the rheostat reading. Great care has to be taken in making the test, as it is a difficult one with which to obtain reliable results. The best condition is when the fault is close to the testing end and when its resistance remains reasonably constant.

(30) *Example.*

Cable: TSX—MR. Locality: Tested from L.P. 52 S. Mimms to L.P. 51. Distance: 1.6 miles. Conductor: 40 lb.

Let X be distance to the fault; L length to far end; *r* the high resistance; R_c the balancing resistance in the closed condition, which is approximately equal to r; and R_o the balancing resistance in the open condition.

$$\text{Then } L - X = L\sqrt{\frac{R_o}{R_c}} \text{ miles, yards or other units.}$$

Closed balance.	Open balance.	(L—X)—distance from L.P.51.	(X)—distance from L.P.52. Miles.	Yards.
110 ohms	94.5 ohms	1.48 miles	0.12 =	211
55*	44	1.43	0.17 =	300
56	47	1.46	0.14 =	246
56	47	1.46	0.14 =	246

* Note the sudden variation in the resistance between first and second tests.

Joint opened 226 yards from L.P.52—fault towards L.P.51
Do. 402 do. — do. L.P.52

The fault was in the length of cable 30 yards from the first joint or 256 yards from L.P.52.

(40) *Localisation of a High Resistance in a Conductor in a Long or Loaded Length of Cable.*

The following method is due to Capt. F. Reid:—

Apparatus required: Wheatstone bridge, high voltage battery reversing key, galvanometer. A "Paul" unipivot was used in the example given, but greater sensitivity may be secured by using a reflecting galvanometer.

The core of M.T. cable is taken and each of the pairs is looped separately at the distant end. See Fig. 9.

The loop resistance of the good loop is measured. The bridge is connected as for a Varley test, but the "good" wire is connected to the rheostat. The loop resistance of the faulty loop, less the resistance of the good loop, is the resistance of the fault.

The battery is then connected to the good loop (as in a Varley test) and is reversed. The rheostat of the bridge is adjusted until no "throw" is visible on the galvanometer when the battery is reversed. The faulty loop resistance is again taken (to ascertain if the fault has changed) and the test repeated several times.

Let R_1 be the resistance of the good loop, R''_1 the resistance of the faulty loop, r the resistance of the fault, X the distance from the testing end to the fault, L the length of the section, and R_4 the balancing resistance.

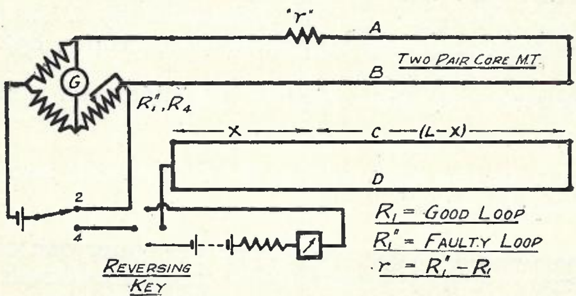
Then $r = R''_1 - R_1$.

The capacity charging current of the good wire flows through R_4 and that of the line between the fault and the distant end through r; the voltage drop in these two resistances has therefore to be equal.

Hence $R_4 L = r(L - X) = (L - X)(R''_1 - R_1)$.

or $L - X = \dfrac{LR_4}{r} = \dfrac{L \quad R_4}{R''_1 - R_1}$ miles, yards or other unit of distance from the mar end.

HIGH RESISTANCE. LONG LOADED LENGTH (Reid)



$$(L-X) = L\frac{R_4}{R_1''-R_1} \qquad X = L\,\frac{R_1''-R_1-R_4}{R_1''-R_1}$$

FIG. 9.

(41) *Example.*

Date, 27/10/21.

Cable: TSX—MR. Tested from L.P. 43 to L.P. 31.

Distance = 19.2 miles, or 12 loading sections.

R_1, the resistance of the good loop, was 936.1 ohms.

Faulty Loop (R''_1) Ohms.	r = Fault ($R''_1 - R_1$) Ohms.	Balancing Resistance (R_4) Ohms.	Distance from Far end. ($L - X$) Miles.	Distance from Near end. (X) Miles.
1017.5	81.4	60	14.2	5.0
1024	87.9	59	12.9	6.3
1024.4	88.3	61	13.2	6.0
1024.7	88.6	58	12.5	6.7
1020.7	84.6	61	13.0	5.4
1020.7	84.6	59	13.4	5.8
1019.7	83.6			

Fault actually found 12.8 miles from Far End.
6.4 miles from Near End.

Joint opened at L.P.40 (this had just been made) 14.4 miles from distant end; fault towards distant end. On retesting from here R_1, good loop, 700 ohms; faulty loop, 785 ohms; balancing resistance, 77 ohms; locating fault 13.05 miles from distant end, or 1.35 miles from testing point.

The next point opened was L.P.39 (1.6 miles from last testing point) and the fault was discovered in the loading pot.

(42) *Locating a Split Pair in a Loaded Cable.*

When a pair has been split in a loop-loaded cable, the number of coils split can be discovered by a simple test. (For full description see Appendix VI., Section 63).

Apparatus required: Battery, galvanometer and reversing key.

Bunch the two split pairs at the distant end, also bunch a good two-pair core.

Take the good core and reverse the battery on one pair; no "throw" will be observed on the galvanometer on the other pair. Split the pairs at the testing end and reverse the battery on two wires; the "throw" on the galvanometer on the other two wires is due to the mutual induction of all the loading coils, hence the "throw" per coil may be calculated. The faulty core is taken and tested in every combination, the direction of the "throws" being noted as one may be negative.

Then one "throw" will be proportional to the number of coils split, one to the total number of coils less the number split and one to the total number of coils less twice the number split—the last reading may be negative. The first two readings may be identified as they will add up to the figure obtained on splitting the pairs of the good core. From these readings the number of coils split may be readily calculated. If the split has been corrected by the jointer at a subsequent joint, the only information furnished by the test is the number of coils split. In the absence of further information, the points where this has been done will not be given by the test; it is possible to make a location, but the test is tedious and needs special apparatus.

(43) *Arrangements Suggested for dealing with Main Cable Faults.*

In the case of a total breakdown (due to wet) in almost any one of the cables radiating from London, a network exists which will enable a loop to be made up by means of which the fault can be localised by a Varley test.

There are also various overhead routes which may be utilised for the same purpose.

It is suggested that certain pairs in the cables and certain wires on the overhead lines should be allocated for use in an emergency of this kind, for the purpose of making up loops or speaker circuits whilst testing. This would, of course, necessitate arrangements with other Districts and also, possibly, with the Engineer-in-Chief.

Bearing in mind the time lost when localising wet faults, in making arrangements both with the Traffic Department and with Engineers in other Sections and Districts (even when armed with the authority of the Engineer-in-Chief) a scheme arranged on these lines should save considerable time where such saving is of vital importance. It might in some cases be possible to organise the arrangements in such a manner that the working of circuits taken was not affected. For instance, the phantom circuits in the TSX—BM—LV cable are insulated by means of transformers at the ends; by entering on the peak of the phantom circuit a single line consisting of the four wires in parallel is obtained. Care must be taken to see that the insulation of the transformers is satisfactory; it will not always be found so good as to enable precision tests to be made. In the latter case the faulty cable will ordinarily be in good enough condition to admit of a "good" loop being found in the cable itself.

It would probably be necessary to rehearse the testing conditions occasionally to ensure that all officers concerned knew their duties thoroughly.

In two Districts the Superintending Engineer has allocated a telegraph address to the trained maintenance officer; it is "Inspector Main Cables. . . ." If all the other Districts used the same form of address, communications on this type of work would be expedited.

Suitable arrangements for the transport of jointers, tools and stores are also necessary when clearing faults. For example, a length of cable of suitable type might be held in stock at a convenient point or, alternatively, the point where such cable is held should be known and recorded in order that time may be saved when it is urgently wanted.

In one case, about 320 miles of circuit were rendered useless for some time, due to the number of pairs in a short piece of cable which was inserted in a main cable being less than the total pairs in the main cable.

Spare loading pots might also be held in suitable places.

In a recent case it took two months to replace a faulty loading pot, even when the pots were available and had not to be specially manufactured; fortunately the circuits were not working and were not required. In another case a faulty pot was replaced by a pot which happened to be available for another work 14 miles away. At 10 a.m. on a Friday notification was received that the pot was at the railway station. By 3 p.m. Saturday the coil was in situ and joined into the main cable. This shows what can be done with good organisation and workmen who are efficient.

(44) *Records of Main Cables.*

It is important that proper cable records should be available at all the principal points where testing may be done. The records should show, amongst other things, the type of cable, loading coils, pairs loaded, distances, etc. Records of loop resistances made at different times in the year are extremely useful.

(45) *Maintenance Tests.*

Periodical tests of the insulation of certain pairs in main cables are required. The loop resistance of certain pairs should also be periodically measured. As the insulation tests are the basis of precision fault locating, they should be under the direct supervision of the trained maintenance officer in the District. In order to standardise methods it is proposed to lay down the rule that the insulation will be measured A to B earthed and B to A earthed. As the insulation of the cable wires up to 100 miles exceeds 100 megohms it is necessary to use a megger which will read insulation of this order. The 250-volt megger only reads up to 20 megohms, a 500-volt megger is therefore required. On account of the risk of damage to loading coils, etc., the use of this megger should be restricted to qualified officers. On account of the fatigue experienced in making several tests at a time and the need of accurate and steady readings, motor-driven 500-volt meggers are now being supplied: particular care is necessary, after the megger comes to rest, to allow time for the charge on the line to dissipate itself before disconnecting the line.

It is also suggested that a cross-talk set, similar to those used by the Engineer-in-Chief's Research Section, would form a useful adjunct at a repeater station or other important office for the quantitative measurement of any disturbance or over-hearing trouble.

In conclusion, I have to thank all the officers who have helped me in writing the paper, furnishing information, lending lantern slides, making diagrams, etc.

APPENDIX I.

(46) *The Trunk Cable Resistance Test Set.*

This set consists essentially of a Wheatstone Bridge with certain arrangements added to secure rapidity in operation. See Fig. 1.

Two pairs of leads connect the set to the four wires comprising a core of Multiple Twin Cable.

A switch is provided which, in one position, joins pair A—B to the set and, in the other position, the C—D pair; in addition, the switch joins one wire of the pair not under test (the C or A) to a special terminal for a purpose which will be mentioned later. (Ratio and Varley Tests.)

In an intermediate position the bridge is disconnected.

A separate box contains the bridge, which is of the "Decade Dial" pattern. Two dials form two ratio arms which may be adjusted to 10, 100 or 1000 ohms as may be required. The variable arm of the bridge consists of five dials giving, in ohms, thousands, hundreds, tens, units and tenths. A dial switch is also fitted which, in one position, for "Loop" tests, short-circuits a slide wire connected between the two ratio arms, and in the other position, for "Ratio" tests, short-circuits the variable arm of the bridge. In an intermediate position (not frequently used) neither the slide wire nor the variable arm of the bridge is short-circuited.

A Paul Unipivot Galvanometer, Pattern "L," of 40-60 ohms resistance, is connected across the two ratio arms; by means of two telephone type keys, contained in the same box as the AB—CD switch, the galvanometer may be disconnceted, shunted with any of three values of shunt or joined to the bridge direct. Convenient shunts are 1/2, 1/10 and 1/100.

Another box contains a slide wire consisting of a wire of 2 ohms resistance, the active or useable portion of which, having a resistance of one ohm, is inserted between the ratio arms. A graduated scale is provided, one portion being adjustable; a cursor, which makes contact with the slide wire, is movable along this scale.

In the switch box a battery key is provided which, in the "Loop" position, connects a battery between the slide wire cursor (*i.e.*, the common point of the ratio arms of the bridge) and the junction of the variable arm of the bridge and the A or C wire coming from the AB—CD switch. In the centre position of the key the battery is disconnected. In the "Ratio" position the battery is joined between the cursor of the slide wire (as before) and the special terminal on the AB—CD switch mentioned previously, in order to feed battery to the distant end over one of the wires not under test. (The battery key forms a useful means of carrying out Varley tests. In the case of a contact the faulty wires are connected to A and B of the AB—CD switch and the wires to which the faulty wires are respectively looped at the distant end are connected to B and D, with the battery key at "Loop," the loop resistance is measured and, with the key at "Ratio," battery is sent *via* contact and thus the Varley reading is obtained. In the case of an earth, the faulty wire is connected to A, the return wire to B and earth to C.)

The resistance measurements of the A—B and C—D loops are straight forward—it is necessary only to operate a switch which short-circuits the slide wire, manipulate the battery key and obtain a balance on the bridge for the A—B loop: the C—D loop is measured by turning the AB—CD switch so as to connect the C—D loop to the bridge.

For the "Ratio" or "Differential" test, two arms of the bridge are formed by the two wires of a pair (A—B or C—D as the case may be) and the other two arms by the two ratio arms of the bridge and the slide wire; the variable arm of the bridge being short-circuited by turning to "Ratio" the switch (which, in the "Loop" position, short-circuits the slide wire).

Calling x the reading in ohms from the centre of the slide wire we have for balance, assuming that 100-ohm ratio arms are used:—

$$\frac{\text{Resistance of A}}{\text{Resistance of B}} = \frac{101 + x}{101 - x}$$

Hence $(A - B) / (A + B) = x/101$: if x has the value of 0.505 ohm, $(A - B) / (A + B)$ has the value of 0.5%. Two scales are provided, one for use with 100-ohm arms and the other for use with 10-ohm arms, the graduations being so designed as to read the percentage unbalance direct without calculation. The scales are adjustable for zero, the adjustment being made by taking two readings—AB shraight and AB crossed—and adjusting the zero to lie half way between; thus any slight error in the ratio arms or testing leads may be compensated.

With this set on a loading section of cable, one two-pair core a minute may be tested, including the time taken by the jointer to change the leads—that is, two loop readings and two ratio readings. In testing, the loop reading of the A—B pair is taken, then the loop reading of the C—D pair, the switches are changed to ratio and the C—D pair ratio test is made, followed by the A—B pair ratio test. When testing the second core the A—B ratio test is made first, followed by the C—D pair ratio, C—D pair loop and A—B pair loop. This involves the minimum operation of the switches.

APPENDIX II.

(47) *The Inductance Testing Set.*

Conductor resistance and inductance tests on loaded cables are made generally on the lines of the conductor resistance tests described in Appendix I., with certain additional appartus and tests. See Fig. 10 and 11.

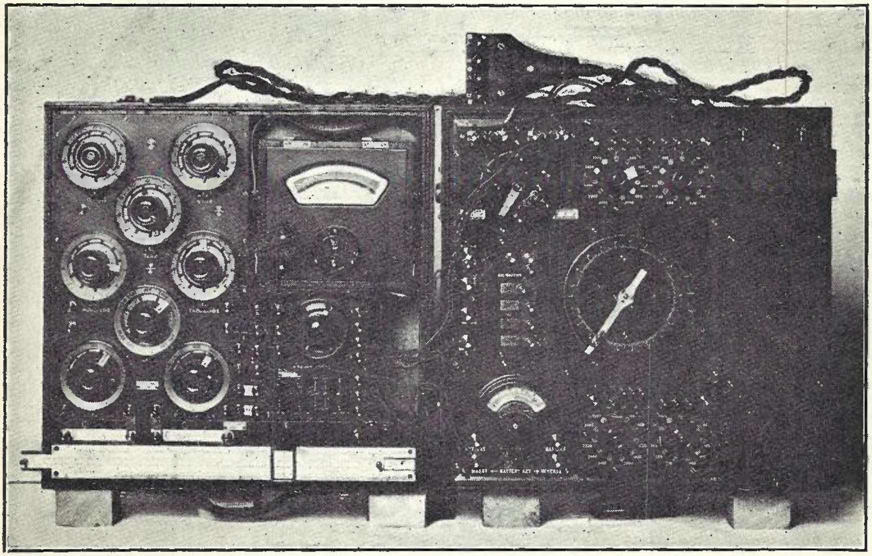


FIG. 10.

Apparatus required :—

(1) Trunk Cable Resistance Set.

(2) Auxiliary Box for Inductance Tests.

The auxiliary box contains the following apparatus:

(1) $7\frac{1}{4}$ μF condenser or 10 + 6 + 4 + 2 μF condenser.

(2) Detector No. 2, or Milliameter, Weston Type, 0-50 milliamperes.

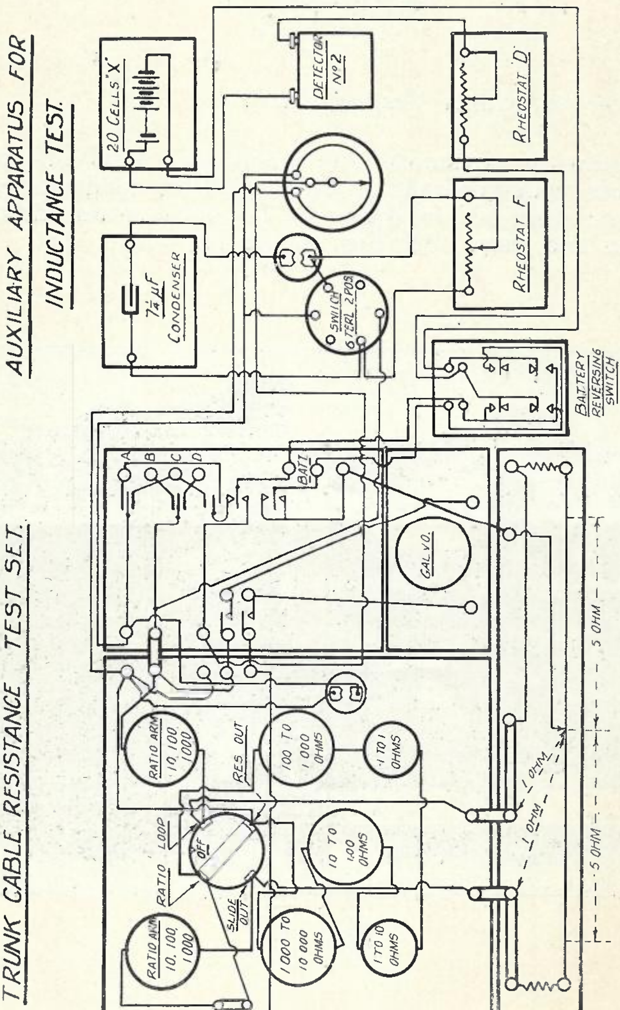


Fig. 11.

(3) Rheostat, F.

(4) Rheostat D or Rheostat F.

(5) Slide wire (circular).

(6) Switch, 6-Terminal, 2-Position.

(7) Key, Telephone type, 28A.

(8) Battery of 20 " X " or " W " type cells.

(9) Plug and short-circuiting block for cutting out the slide wire when making ratio tests.

(10) Plug and block for cutting in and out the condenser.

The apparatus is connected up in accordance with Fig. 11.

The battery of 20 " X " or " W " size dry cells supplies current to the bridge of the Trunk Cable Resistance Test Set: the Rheostat, D, regulates this current, 5, 10, 20 or 25 milli-amperes being suitable values.

The Detector No. 2 (50 milli-ampere scale) or Weston Milliammeter is used to measure the current, and the Key 28A is used to connect, disconnect or reverse the battery current with respect to the bridge.

The Circular Slide Wire is connected between the AB—CD switch of the resistance test set and the variable arm of the bridge. The battery connection is made to the slider instead of the terminal of the variable bridge arm, thus inserting part of the slide wire in the cable loop and the other part in the variable bridge arm: this is to enable an exact balance to be obtained, the variable arm of the bridge only being adjustable to tenths of an ohm.

The Rheostat, F, is connected across the bridge terminals of the AB—CD switch (so that the slide wire comes between it and the bridge), by means of the 6-Terminal 2-Position Switch, as a substitute for the loop resistance of the line when the cable is open at the far end, and also when calibrating the bridge.

A final balance between the Bridge and the cable loop or Rheostat, F, is obtained on the slide wire to less than one-tenth of an ohm.

The $7\frac{1}{4}$ μF or $10 + 6 + 4 + 2$ μF Condenser is connected in parallel with the Rheostat F, by means of the plug provided, when calibrating the bridge.

In addition, plugs may be provided and arranged so that the phantom circuit (*i.e.*, loop formed by A—B and C—D) can be connected to the bridge for measurement.

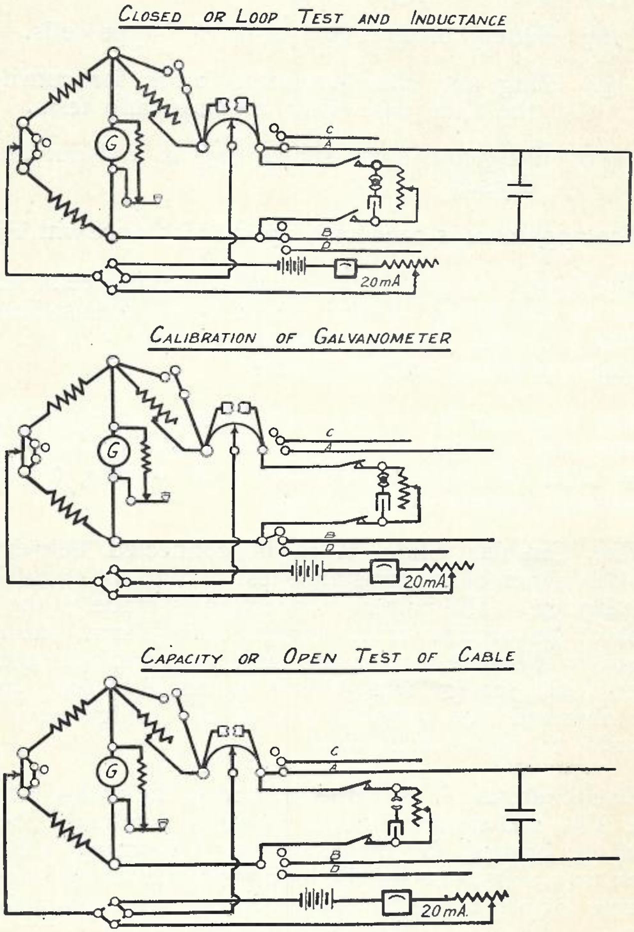


FIG. 12.

Method of Operation. See Fig. 12.

(1) *Loop Resistance and Inductance Test* of the cable loop: by balancing the loop resistance, reversing the battery current and noting the " throw " of the galvanometer.

(2) *Capacity Test*: by substituting for the cable loop the Rheostat F, and disconnecting the cable loop at the distant end, the " throw " of the galvanometer being noted when the bridge current is reversed. In general, this will be in the reverse direction to that in test (1), but on short lengths will be small or even negligible.

(3) *Calibration Test*: by substituting for the cable loop a known ($7\frac{1}{4}$ μF) condenser, the " throw " of the galvanometer on reversal of the battery current being noted as in (2). The direction of the throw will be in the same direction as in (2). This test is only necessary once per set of readings on loops of nominally the same resistance.

The inductance of the loop is given by the formula:—

$$L = \frac{R_1^2 (G_1 - G_k/3)\, C}{G_c 1000} \text{ millihenries}$$

where L = inductance of the loop in millihenries

R_1 = resistance of the loop in ohms.

C = capacity of the Standard Condenser in microfarads

G_c = " throw " in divisions of the galvanometer in test (3) (calibration)

G_1 = " throw " in divisions of the galvanometer in test (1) (Loop closed or Inductance test)

G_k = " throw " of the galvanometer in divisions in test (2) (Loop open or Loop Capacity test).

On long lines of high resistance the loop " throw " in test (1) becomes small and it may even reverse and become negative. The point at which this occurs may be calculated approximately by equating G_1 to zero. If it is remembered that the characteristic impedance Z_0 of a loaded line is approximately $\sqrt{L/C}$ in ohms (where L is the inductance in henries and C the capacity in farads per unit length, the statement may be made that the closed " throw " will be zero when the loop resistance is equal to $\sqrt{3}$ times the characteristic impedance Z_0 of the line.

The following table gives, *approximately*, the length of line where this occurs and the approximate characteristic impedance for different types of loading, assuming a wire-to-wire capacity of 0.065 microfarads per mile :—

Weight of conductor per mile.	Resistance per mile loop (conductor only).	Light Loading 133 mH coils, spaced 2.5 miles Z_0 = 880 ohms. (Add to loop one ohm per mile for loading coils).		Medium Loading 175 mH coils (including phantom) 1.6 miles Z_0 = 1,300. (Add to loop 6.5 ohms/mile).		Heavy Loading 250 mH coils (including phantom) 1.125 miles Z_0 = 1,850. (Add to loop 14.8 ohms/mile).	
		Length for zero throw.	Total loop resistance per mile.	Loop resistance ohms/mile.	Length.	Loop resistance ohms/mile.	Length.
lbs.	Ohms.	Miles.	Ohms.	Ohms.	Miles.	Ohms.	Miles.
10	176	8.6	177	182.5	12.3	191	16.8
20	88	17.1	89	94.5	24	103	31
40	44	33.8	45	50.5	44.5	58.8	54.5
70	25	58.6	26	31.5	71.5		
100	17.6	82.0	18.6				
150	11.7	120	12.7				
200	8.9	154	9.9				
300	5.9	221	6.9				

(48) *Approximate Characteristic Impedance of Lines.*

Table giving the approximate characteristic impedance for loop and phantom circuits, both non-loaded and loaded. The capacity of loop assumed as 0.065 microfarads per mile and phantom as 0.090 microfarads per mile Z_o taken as $\sqrt{\frac{L}{C}}$ for loaded circuits, for non-loaded circuits 800 periods per second is taken as the frequency. The table also shows

Impedance of Non-Loaded Cable Circuits.						
	Side Circuits.			Phantom Circuits.		
Conductor.	Circuit Impedance.		Resistance in ohms to be joined across secondary of repeating coil	Circuit Impedance.		Resistance in ohms to be joined across peaks of repeating coil.
	Ohms.	Angle.		Ohms.	Angle.	
100 lb.	237	$\overline{\backslash 37^{\circ}}$	120	137	$\overline{\backslash 20^{\circ}}$	100
70 ,,	280	$\overline{\backslash 39^{\circ}}$	160	160	$\overline{\backslash 26^{\circ}}$	130
40 ,,	370	$\overline{\backslash 41^{\circ}}$	250	213	$\overline{\backslash 33^{\circ}}$	180
20 ,,	520	$\overline{\backslash 43^{\circ}}$	400	300	$\overline{\backslash 39^{\circ}}$	270
10 ,,	756	$\overline{\backslash 44^{\circ}}$	600	426	$\overline{\backslash 41^{\circ}}$	400

the resistance to be inserted across the windings of two selected 4006A repeating coils on cross-talk distant end set for loop circuits and across the peaks of the line windings for the phantom circuit. The loaded lines have approximately a very small negative angle. (See Fig 13. Cross-Talk distant end set.)

Impedance of loaded cable circuits.

The cut-off frequency $f = \frac{1}{\pi d \sqrt{LC}}$, where d is the spacing of the loading coils in miles and L and C the inductance (Henries) and the capacity (Farads) per mile,

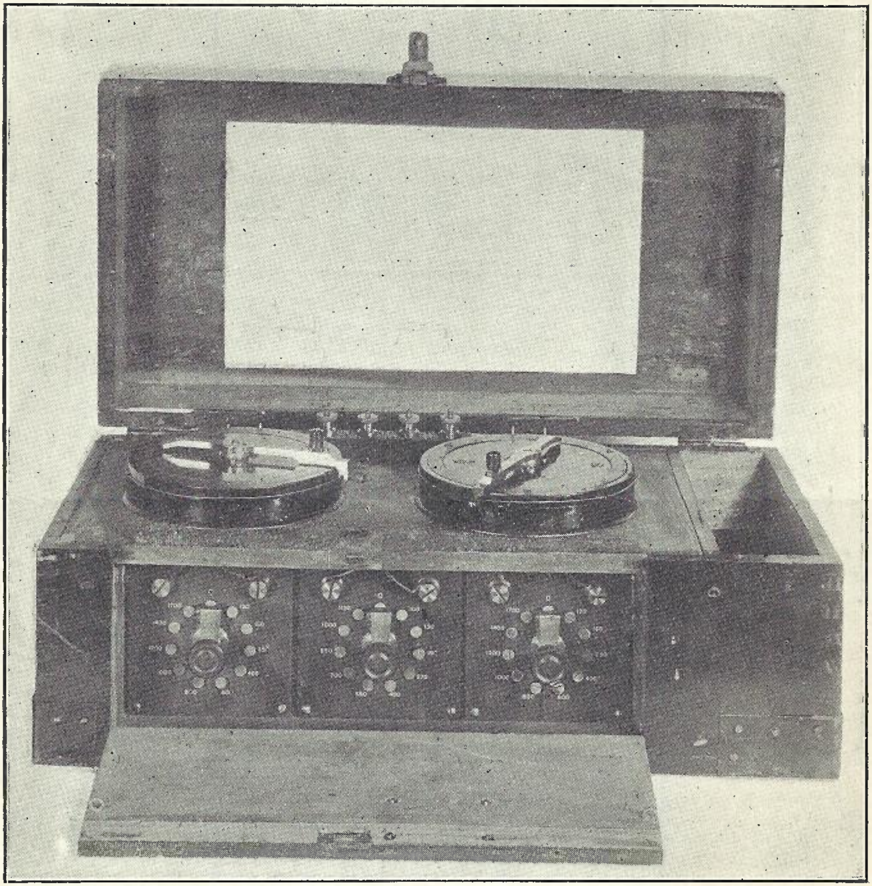


FIG. 13.

respectively. The propagation time, t, in micro-seconds per mile is given by the equation $t = 10^6 \sqrt{LC}$.

Loaded Cable Circuits 10 lb. to 200 lb. Conductors.

The capacity has been taken as 0.065 μF per mile for loop circuits and 0.090 μF per mile for phantom circuits.

COIL SPACING. Miles.	Side Circuits. Inductance of		Cut-off Point.		Propagation time. Micro-seconds per mile.	Circuit Impedance. Ohms.	Resistance in ohms to be joined to peaks of repeating coils.	Phantom Circuits. Inductance of		Cut-off Point.		Propagation time. Micro-seconds per mile.	Circuit Impedance ohms.	Resistance in ohms to be joined to peaks of repeating coils.
	Coil in Milli-henries.	Circuit in Milli-henries. per mile.	Radians per sec.	Cycles per sec.				Coil in Milli-henries.	Circuit in Milli-henries per mile.	Radians per sec.	Cycles per sec.			
1.125	44	39	35 400	5 620	50.5	775	600	25	22.2	39 800	6 320	45	496	400
2.6	133	51	13 300	2 120	57.5	890	800	82	31.5	14 420	2 300	53	590	550
1.125	89	79	25 000	3 980	72	1 100	1 000	54	48.0	27 400	4 350	66	730	700
1.6	133	83	17 000	2 700	73.5	1 130		82	51.3	18 400	2 930	68	750	
1.3	133	102	14 800	2 920	81.5	1 250		83	63	20 400	3 240	75	840	
1.6	175	110	18 350	2 360	84.5	1 300	1 200	106	66.3	16 200	2 580	77	860	850
1.125	133	118	20 400	3 250	87.5	1 350		82	73	22 000	3 500	81	900	
1.3	175	135	16 450	2 620	93.5	1 440	1 400	106	81.5	18 000	2 860	85.5	950	1 000
1.125	175	156	17 750	2 820	101	1 540		106	94.3	19 300	3 080	92	1 020	
1.125	250	222	14 850	2 360	120	1 850	1 700	155	138	15 950	2 540	111.5	1 240	1 200

To find a point of discontinuity in a loaded cable (*vide* I.P.O.E.E. Paper No. 76, "Technical Developments in Telephonic Repeaters since 1917," by C. Robinson and R. M. Chamney. Appendix IV., page 112):—

Fault l miles away $f_1\, f_2$. $\omega_1/2\pi$ $\omega_2/2\pi$ frequencies of humps in impedance frequency curve t = propagation time in micro-seconds per mile from table above.

$$l \fallingdotseq \frac{1}{2\sqrt{\mathrm{CL}}(f_1 - f_2)} = \frac{\pi}{\sqrt{\mathrm{CL}}(\omega_1 - \omega_2)} = \frac{\pi}{t \times 10^{-6}(\omega_1 - \omega_2)} = \frac{10^6}{2t \times (f_1 - f_2)}$$

Transformers for Terminating Cables.

In order to avoid transmission loss circuits differing in characteristic impedance should be joined together by transformers with a suitable ratio of turns.

Transformers. No. 15 (with Stalloy core) for terminating phantom cables; No. 16 (with Stalloy core with air gap) for terminating phantom cables; for duplex Repeaters two paired transformers, one transformer for the line, the second for the balancing network.

Winding ratio $= n$.	Ratio of Impedances $\frac{Z_1}{Z_2} = n^2$
Turns 1 to n.	1 to n^2
Type A 1 to 1	1 to 1
B 1 to 1.27	1 to 1.61
C 1 to 1.62	1 to 2.63

APPENDIX III.

(49) *The Cross-Talk Set.*

The cross-talk set (Figs. 14 and 15) consists of a cross-talk meter, repeating coils, and keys so connected that when alternating or speech currents are fed to it (from an outside source) the cross-talk between the three circuits in a two-pair core and also between the circuits in this core and any one other core may be rapidly measured. The measurement is made by listening on a standard 60-ohm Bell receiver (not included in the set) and comparing the disturbance heard when listening on the disturbed circuit with the nearest reading on the meter.

The function of the Telephone Type Keys 28A is as follows:—

Counting from the left, the first key applies the disturbing current through specially selected 4006A repeating coils to the A—B loop, phantom or C—D loop; the second key connects the third telephone key to either of the three aforementioned circuits; the third or telephone key connects the listening telephone to the second key for listening on the circuits of the core under test or to the cross-talk meter or to the fourth key; the fourth key connects the A—B, phantom or C—D circuits of the second core, *via* the third key, to the telephone in order to determine whether any of the circuits of the first core is disturbing any of the circuits of the second core and to enable any disturbance to be measured.

The tests are made with the distant end (1) open and (2) closed with repeating coils and resistances which represent the characteristic impedance of the line as far as possible. (See Fig. 13). The purpose of the fifth key is to indicate to the testing officer that these coils and resistances, known as a "Distant End Set," have been correctly connected by the jointer stationed at the far end of the cable; this is accomplished by passing a current from two small cells through a milliameter, out on one pair to the far end of the cable and back on the other pair.

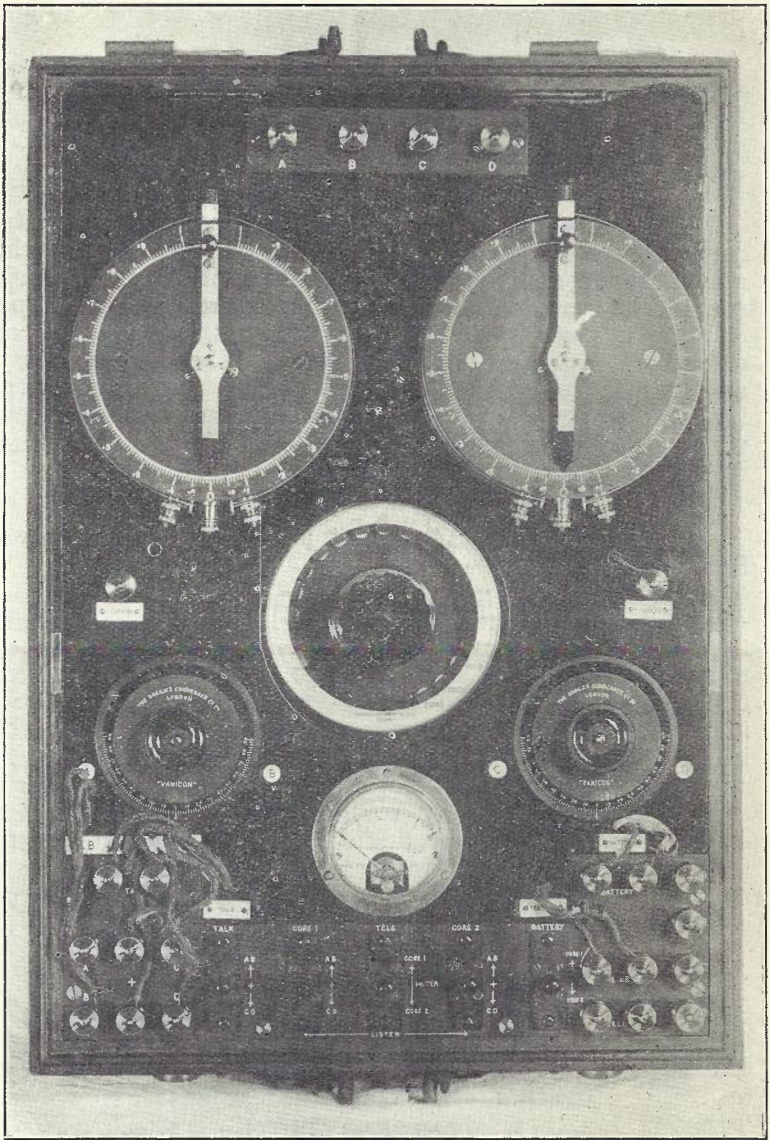


FIG. 14.

The fifth key in one position sends out this current on the core under test; in the middle position the "key" is "Off"; and in the third position current is passed along the second core in a similar manner.

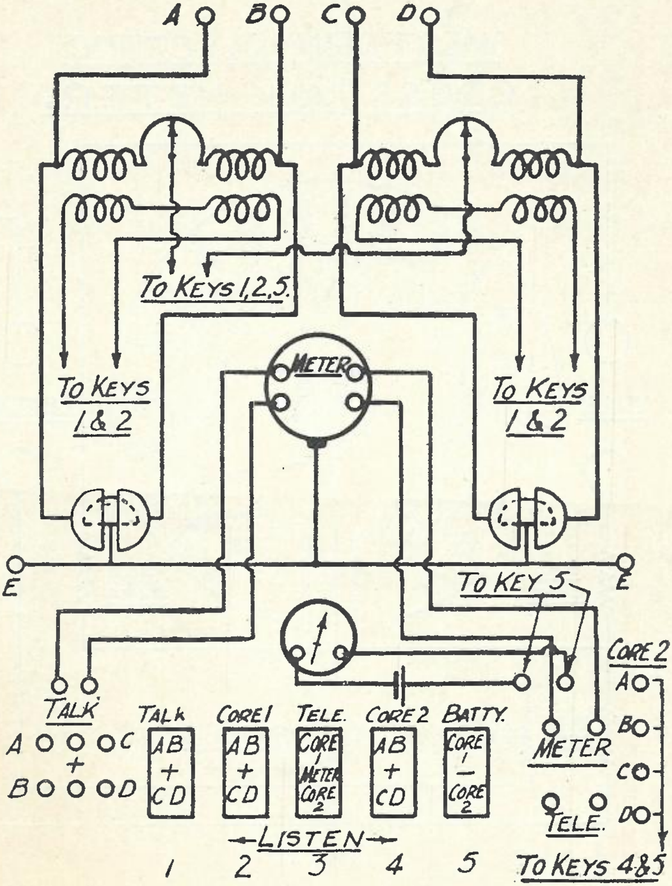


Fig. 15.

A complete set of apparatus consists of batteries, reed hummer, screened transformer, cross-talk set, distant end set, suitable leads and clips, and a selected 60-ohm standard Bell receiver.

(50) *The Cross-Talk Meter. Table of Resistances and Comparative Standard Cable Values Corresponding to the Various Readings.*

The equivalent standard cable values are calculated for a frequency of 800 cycles per second and are such that the

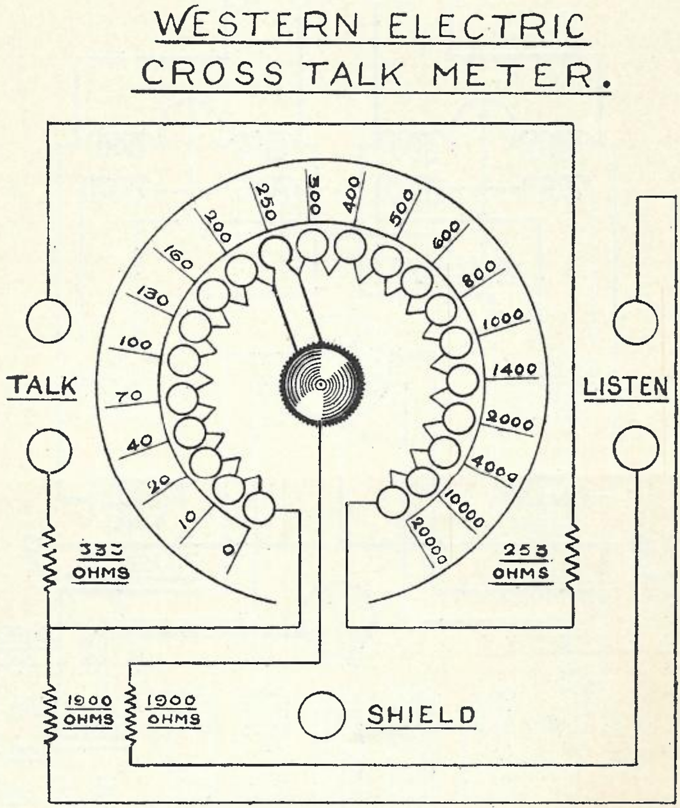


Fig. 16.

current would be attenuated to the same amount as the current in the telephone of the cross-talk meter. See Fig. 16.

The resistance between the talk terminal and zero is 333 ohms, the resistance from zero to 20,000 is 80 ohms, and from 20,000 to the other talk terminal is 253 ohms; thus making a total of 666 ohms between the terminals. In each leg of the receiver circuit a resistance of 1,900 is placed; thus there is 3,800 ohms in series with the telephone receiver, shunting the resistance shown in the table above.

Reading of Meter.	% of meter current in telephone.	Equivalent TU.'s	Equivalent M.S.C at 800 cycles B=0.106	Resistance bridged by telephone Ohms.	Resistance added from last step Ohms.
0	0.0		∞	0.00	0.00
10	0.001	100	108.6	0.04	0.04
20	0.002	94	101.9	0.08	0.04
40	0.004	88.6	95.5	0.16	0.08
70	0.007	83.1	90.3	0.28	0.12
100	0.010	80	86.9	0.40	0.12
130	0.013	77.7	84.5	0.52	0.12
160	0.016	75.9	82.4	0.64	0.12
200	0.020	74	80.3	0.80	0.16
250	0.025	72.0	78.3	1.00	0.20
300	0.030	70.5	76.5	1.20	0.20
400	0.040	68	73.7	1.60	0.40
500	0.050	66.0	71.7	2.00	0.40
600	0.060	64.4	69.9	2.40	0.40
800	0.080	61.9	67.2	3.20	0.08
1000	0.100	60	65.2	4.00	0.80
1400	0.140	57.1	62.0	5.60	1.60
2000	0.200	54.0	58.6	8.60	2.40
4000	0.400	48.0	51.1	16.00	8.00
10000	1.000	40	43.45	40.00	24.00
20000	2.000	34.0	36.9	80.00	40.00

APPENDIX IV.

Notes on Apparatus which is useful for Testing and which could be readily constructed or made available in a District.

(51) *List of Portable Apparatus suitable for Emergency Faults.*

(1) Post Office Wheatstone Bridge.

(2) Paul Unipivot Galvanometer, Pattern "L." This galvanometer is about twice as sensitive as the small round brass pattern usually supplied.

(3) Detector, No. 2, with, say, two or three "X" type dry cells for tapping out, picking up wires, etc. (The "X" cells can conveniently be placed in a small box with terminals on the outside).

(4) A box containing four Keys, Telephone Type, 28A with resistances. (See Fig. 17). This box would probably have to be made up locally; its use, in conjunction with the bridge, about doubles the degree of accuracy obtainable in simple loop tests, besides protecting the galvanometer from damage. The purpose of the first two keys is to control the galvanometer: the first key disconnects the galvanometer from the bridge, shunts it with three values of shunt (obtained on the second key) or connects the galvanometer directly to the bridge; the second key connects three values of shunts to the galvanometer when the first key is in the middle position. (Suitable values suggested for the shunts are 1/3, or 1/2, 1/10 and 1/100.) The last two keys are for controlling the battery current: the third key connects the battery to the bridge for loop tests, to earth or the wire in contact for Varley tests, and in the third position to the second good wire for the test outlined in Section (24) of the paper or the test given in Technical Instruction IV., Para. 103, amendment 3/20; the last key reverses or disconnects the battery.

(5) A box containing 10 dry cells "Y," with a suitable resistance for cutting down the battery current to a suitable value.

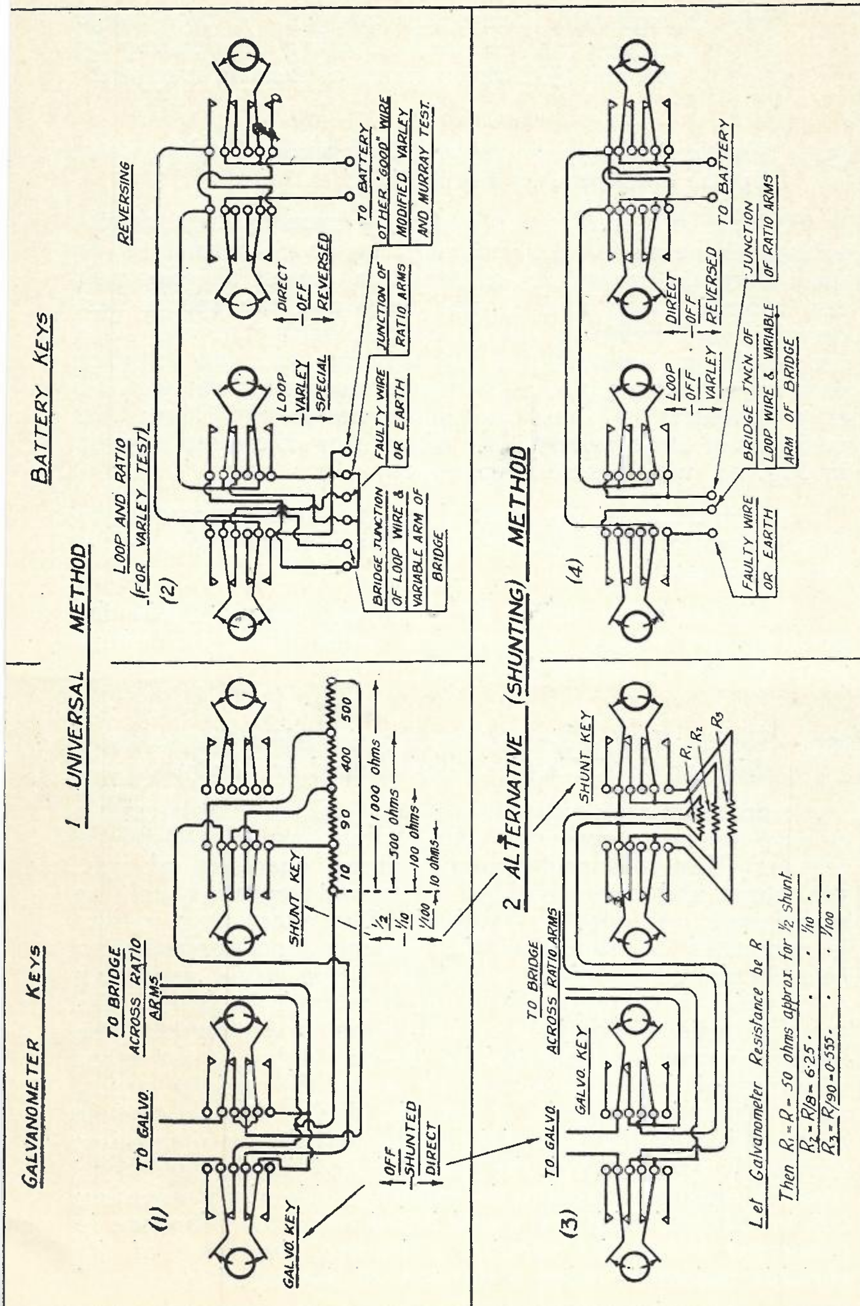

1 UNIVERSAL METHOD
GALVANOMETER KEYS
BATTERY KEYS
(1)
TO GALVO.
TO BRIDGE ACROSS RATIO ARMS
SHUNT KEY
10
90
400
500
1 000 ohms
500 ohms
100 ohms
10 ohms
½
1/10
1/100
OFF
SHUNTED
DIRECT
GALVO. KEY
(2)
LOOP AND RATIO (FOR VARLEY TEST)
REVERSING
LOOP
VARLEY
SPECIAL
DIRECT
OFF
REVERSED
TO BATTERY
OTHER "GOOD" WIRE MODIFIED VARLEY AND MURRAY TEST.
JUNCTION OF RATIO ARMS
FAULTY WIRE OR EARTH
BRIDGE JUNCTION OF LOOP WIRE & VARIABLE ARM OF BRIDGE
2 ALTERNATIVE (SHUNTING) METHOD
(3)
TO GALVO.
GALVO. KEY
TO BRIDGE ACROSS RATIO ARMS
SHUNT KEY
R1
R2
R3
(4)
LOOP
OFF
VARLEY
DIRECT
OFF
REVERSED
TO BATTERY
JUNCTION OF RATIO ARMS
BRIDGE J'NCN. OF LOOP WIRE & VARIABLE ARM OF BRIDGE
FAULTY WIRE OR EARTH
Let Galvanometer Resistance be R
Then $R_1 = R = 50$ ohms approx. for ½ shunt.
$R_2 = R/8 = 6{\cdot}25$ · · · 1/10 ·
$R_3 = R/90 = 0{\cdot}555$ · · · 1/100 ·

FIG. 17.

(6) A high and a low range megger. A high range megger with a switch dividing the reading by 100 will fulfil the purpose of the two meggers.

(52) *Simple Bridge made up with Differential Galvanometer by the addition of a Rheostat, F.*

It does not seem to be generally known that a simple bridge can be made up by the addition of a Rheostat, F, to the differential galvanometer found in almost all telegraph test rooms. Loop and Varley tests and the special test described in Section 24 may be carried out by its use. The use of the galvanometer in this manner does not interfere with its normal functions: all that is required is the addition of a Rheostat, F, and the appropriation of U-link test positions of three spare lines. The wiring of the set is given in Fig. 18, which is self-explanatory.

A set made up on these lines had been in use at the Fenny Stratford test hut for some considerable time, before the author saw it.

It is extremely useful in indicating approximately the position and nature of faults on aerial lines, for which purpose it is in almost daily use.

(53) *Simple Cross-Talk Set for use in Indicating when a Line or Cord Circuit is Unbalanced or Faulty.*

Apparatus required:—Source of A.C. such as a buzzer or tone test in an exchange, 4006A repeating coil, telephone receiver, Key 28A, and two resistances, one fixed of, say, 500 ohms and one variable. A second repeating coil or transformer may also be required. The alternating current is connected by means of the last-mentioned transformer between the centre of the windings of the 4006A repeating coil, which are connected to the line under test, *via* the 500-ohm resistance and the variable resistance to earth. The telephone may be connected by the key either to the other windings of the repeating coil or across the variable resistance. In order to make a test, the faulty line or cord is connected to the line side of the repeating coil, the alternating current is applied and the sound heard in the telephone receiver when connected to the exchange side of the repeating coil is balanced with the sound heard when the telephone is connected across the variable resistance, the value of the variable resistance being a measure of the out-of-balance of the line. This set is essentially a crude form of cross-talk meter.

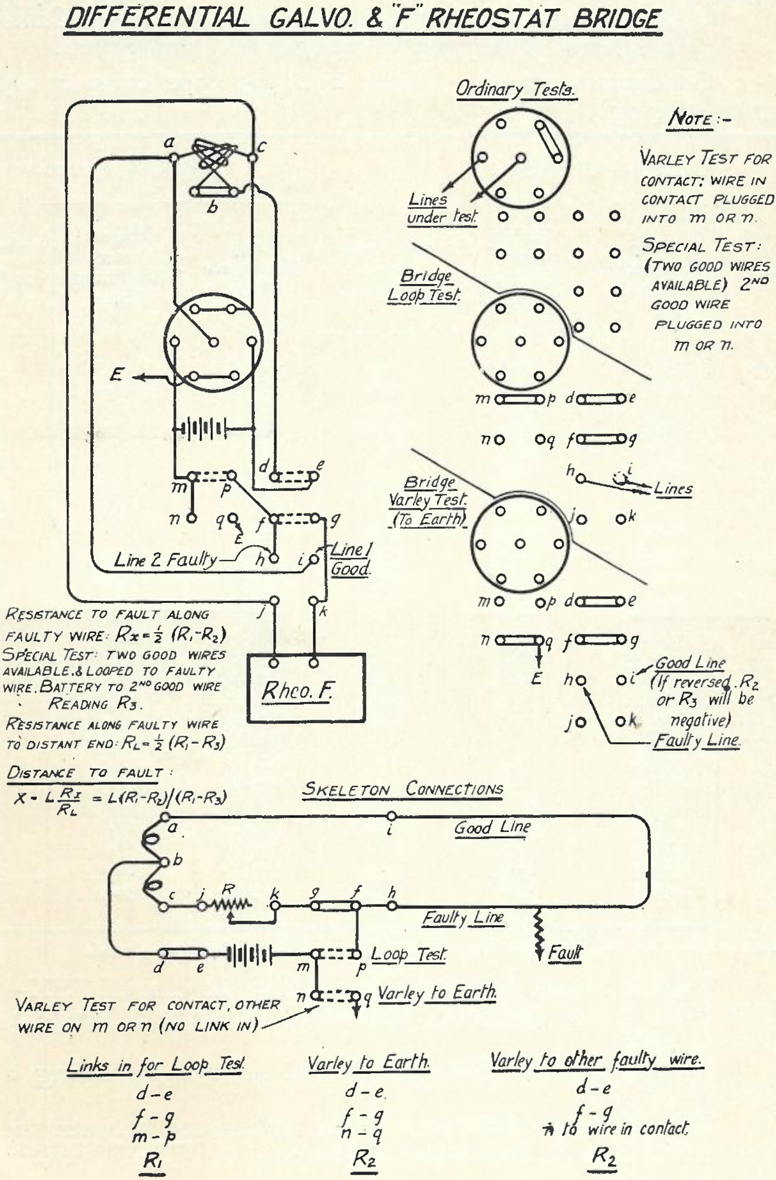


FIG. 18.

APPENDIX V.

(54) *Table showing the Variation in the Resistance of a Loop in the London—Birmingham—Liverpool Cable at different Dates due to changes in Temperature.*

Conductors 200-lb., loaded with 535 type coils at 2.5 mile spacing.

	TSX—BM Section.			BM—LV Section.		
Date.	Loop Resistance Ohms.	Excess over Minimum Ohms.	Per Cent above Minimum.	Loop Resistance Ohms.	Excess over Minimum Ohms.	Per Cent above Minimum
May, 1920.	1029	19.3	1.92	842.5	14.5	1.75
June, ,,	1048.1	38.4	3.82	857.5	29.5	3.55
July, ,,	1053.3	43.6	4.34	860	32	3.86
Sept., ,,	1048	38.3	3.20	856.2	28.2	3.40
Nov., ,,	1038	28.3	2.81	850	22	2.66
Jan., 1921.	1020	10.3	1.03	836.4	8.4	1.01
Feb., ,,	1011.6	1.9	0.19	829.6	1.6	0.19
Mar., ,,	—	—	—	836	8.0	0.98
Nov., ,,	1022	12.3	1.22	837	9.0	1.09
Jan., 1922.	1009.7	0.0	0.00	828.0	0.0	0.00
Mar., ,,	1014.9	5.2	0.52	831	3.0	0.36
July, ,, *	1047.5	37.8	3.76	856.4	28.4	3.43
Aug., ,,	1051.8	42.1	4.18	860.3	32.3	3.90
Sept., ,,	1047.14	37.4	3.72	856.2	28.2	3.40
Oct., ,,	1039.55	29.8	2.96	850.0	22.0	2.66
Nov., ,,	1020	10.3	1.02	837.5	9.5	0.80
Dec., ,,	1016	6.3	0.63	834.6	6.6	0.80
Jan., 1923.	1012.4	2.7	0.27	831.25	3.3	0.40
Feb., ,,	1014.9	5.2	0.52	832.6	4.6	0.55
Mar., ,,	1013.1	3.4	0.34	831.3	3.3	0.40
April, ,,	1021.5	11.8	1.17	836.67	8.7	1.05
May, ,,	1037.7	28.0	2.78	848.3	20.3	2.45
June, ,,	1038.8	29.1	2.89	851.75	23.8	2.88
July, ,,	1057.0	47.3	4.70	864.6	36.6	4.42
Aug., ,,	1062.6	52.9	5.25	867.0	39.0	4.70
Sept., ,,	1049.5	39.8	3.96	858.7	30.7	3.70

* From this date the figures have been added since the paper was read.

The maximum difference observed in the case of TSX—BM cable is 5.25 per cent., indicating a change of temperature of 24°F.

In the case of BM—LV cable, 4.70%, indicating a change of 22°F.

The maximum difference in the percentage between the two cables is 0.48, indicating a difference of 2°Fah. between the two cables.

The maximum and minimum figures underlined.

APPENDIX VI.

Summary of Formulæ and Apparatus required for carry out the Tests described in the Paper.

(56) *List of Symbols employed.*

R_1 = loop resistance of loop in ohms.

R''_1 = ,, ,, of faulty loop in Capt. Reid's test.

R_2 = balancing resistance in Varley test, measuring from near end.

R'_2 = ditto ditto from distant end.

R_3 = balancing resistance in special test (battery to second good wire).

R_4 = ditto Capt. Reid's test for localising a high resistance in the conductor.

P/Q = ratio in Murray test, testing from near end. P connected to faulty line.

P'/Q' = ditto testing from distant end.

X = distance to fault from near end (miles, yards or other length units).

L = length of line near end to distant end.

R_x = resistance in ohms from near end to fault measured along faulty wire.

R_l = resistance in ohms measured along faulty wire from near end to far end.

r = resistance lumped in conductor or high resistance at a point.

$R_{(l-x)}$ = resistance in ohms from fault to far end.

R_o, R_c = balancing resistance in the open and closed test for locating a high resistance in a short length of cable.

M = insulation of good wire. (Ohms Megohms).

F = ditto of faulty wire.

C_m = capacity to be measured.

C_s = standard capacity.

A/B = bridge ratio arms when unequal; A connected to variable arm of bridge.

(57) *The Varley Test.*

Apparatus:—Bridge megger and resistance box (with addition of special switching key, if required, for rapid operation for insulation, loop and Varley tests); or bridge, galvanometer, battery (and, if required, special switching keys for galvanometer and battery); or, for rough tests, a differential galvanometer, resistance box and battery.

Test (1) Loop resistance, (2) Varley: battery to earth.

General Case Unequal Ratio Arms.

$$R_x = \frac{R_1 - R_2 \dfrac{B}{A}}{1 - \dfrac{B}{A}} \text{ ohms.}$$

When faulty wire is joined to ratio arm for balance.

$$\text{Then } R_x = \frac{R_1 + R_2}{1 - \dfrac{A}{B}}$$

Special Case Equal Ratio Arms.

$$R_x = \tfrac{1}{2}(R_1 - R_2) \text{ ohms.}$$

When good and faulty wires have the same resistance and length.

$$\text{“}X\text{”} = \frac{L(R_1 - R_2)}{R_1} \text{ miles or other units of length.}$$

When two good wires are available, which need not be of same gauge as the faulty wire. (Third test, battery to second good wire). All three wires looped at distant end. See Fig. 3.

$$R_x = (R_1 - R_2)/2 \text{ and } R_l = (R_1 - R_3)/2 \text{ ohms.}$$

$$\text{or} \quad X = L\frac{(R_1 - R_2)}{(R_1 - R_3)} \text{ units of length.}$$

In this test, when good and bad wires are of the same gauge, $R_3 = 0$.

Note.—In all tests, except general cases if, for balance, the faulty wire is joined to the ratio arm of the bridge instead of the variable arm, R_2 or R_3, as the case may be, changes sign and becomes negative and has therefore to be added instead of subtracted in the formulæ.

(58) *Special Varley Test (Mr. H. T. Werren's Method) for High Insulation Faults. See Fig.* 5.

Apparatus:—Special bridge, high voltage battery, sensitive reflecting galvanometer, universal shunt, Detector No. 2, resistance 20,000 ohms and battery keys. A supply of paraffin blocks and special G.P. or V.I.R. leads are also required. All apparatus in duplicate as the tests are made from both ends.

$$X = \frac{LR_2'}{R_2' + R_2}$$

Note.—The good and faulty wires must be of the same gauge and resistance and be in the same cable.

(59) *Special Varley Test (See Fig.* 4) *when the good and bad wires are comparable but low compared with the normal Insulation of the Cable.*

Test from one end only: apparatus as above; for faults below one megohm, a Paul Unipivot galvanometer may be used and, on short lines, a megger instead of a battery. The two wires must be of the same gauge and resistance.

$$R_x = \tfrac{1}{2}\left(R_1 - R_2\left(\frac{M + F}{M - F}\right)\right) \text{ ohms.}$$

$$\text{or } R_{(l-x)} = \tfrac{1}{2} R_2 \left(\frac{M + F}{M - F}\right) \text{ ohms.}$$

$$X = \frac{L\left(R_1 - R_2\left(\frac{M + F}{M - F}\right)\right)}{R_1} \text{ miles or other units.}$$

$$\text{or } L - X = \frac{LR_2 (M + F)}{R_1 (M - F)}$$

(60) *The Murray Loop Test.*

Apparatus:—Two resistances or slide wire, battery and galvanometer. (Keys, etc., as required).

The P resistance joined to the faulty wire.

$$R_x = \frac{R_1 P\cdot}{(P + Q)} \text{ ohms.}$$

If both wires are of the same gauge and length (L)

$$X = \frac{2LP}{(P + Q)} \text{ units of length.}$$

(61) *The Precision Murray Test (Mr. H. T. Werren's) when the Fault Insulation is high. See Fig.* 6.

Apparatus :—1000-ohm slide wire, sensitive reflecting galvanometer, shunt, high voltage battery, resistance, Detector No. 2, and battery keys as required. All apparatus in duplicate to test from either end. Both wires must be of the same gauge and length.

$$X = \frac{L(P' - Q')}{(P - Q) + (P' - Q')} \text{ miles, yards or other units.}$$

(62) *Locating a High Resistance in a Conductor.*

(*a*) Long loaded length: Capt. F. Reid's method. Fig. 9.

Apparatus :—Bridge, one cell and high voltage battery, reversing key and two-way key, Unipivot or, preferably, sensitive reflecting galvanometer and shunt.

Alternate loop tests of faulty loop with minimum possible current; and of capacity to other pair of two-pair core by battery reversal; resistance inserted in bridge (R_4) to obtain a balance.

$$L - X = \frac{LR_4}{r} = \frac{LR_4}{R_1'' - R_1} \text{ or } X = L\left(1 - \frac{R_4}{R_1'' - R_1}\right)$$

(*b*) Short non-loaded length: E. S. Ritter's method. Fig. 8.

Apparatus :—Reed hummer, six "Y" cells for same, balanced transformer, non-reactive ratio arms, two air condensers, non-reactive resistance, 100 ohms, reading to tenths of an ohm, telephone receiver, resistance to shunt down reed hummer current.

Test on two-pair core of cable. Alternate tests with distant end open and closed.

$$L - X = L\sqrt{\frac{R_o}{R_c}} \text{ or } X = L\left(1 - \sqrt{\frac{R_o}{R_c}}\right)$$

(63) *The Location of Split Pairs which are caused by Incorrectly Jointing Loading Coils into Cables.*

The simplest case arises when only side circuit coils are involved, the phantom circuits not being loaded. The more difficult case occurs when the phantom circuit is loaded, as the phantom coils upset the simplicity of the tests.

Two principal methods can be employed :—

(1) Assuming that the two split pairs are in a two-pair multiple twin core. (They could equally well be two separate pairs.) The four wires concerned should be bunched at distant end. The inductance of each loop is measured from one end, where the coil is split, one winding will give only one quarter the inductance of the complete coil, which, added to the quarter inductance of the coil in the return loop gives, approximately, one half the normal inductance for every split coil. The number of coils split may thus be calculated. The apparatus used is the inductance testing set employed for testing trunk cables and the test consists of measuring the "throw" in the galvanometer, caused by reversal of a known battery current, when the bridge is connected for measuring loop resistance.

(2) The second method uses simpler apparatus which consists of a battery, reversing key (resistance in series with the battery, if required) and a galvanometer. The two pairs are bunched at the distant end as before. Current is sent round one loop with the galvanometer across the other loop. The "throw" in the galvanometer on reversal of the battery is a measure of the mutual induction between the two loops. When two good loops are taken this will be nil. When one wire of one pair is taken, the return being on one wire of the other pair, the same applying to the galvanometer, the maximum "throw" will be observed—call this lk where l is the number of coils and k the deflection "throw" per coil. When the faulty core is taken the wires are formed into pairs in all combinations and the "throw" is noted.

Let there be l coils and x coils split—the "throw" will be as follows:—

	Wires connected to — Battery.	Wires connected to — Galvanometer.	"Throw" in divisions on Galvanometer.
(1)	A and B or C ,, D	C and D A ,, B	xk
(2)	A ,, D or B ,, C	B ,, C A ,, D	$(l-x)k$
(3)	A ,, C or B ,, D	B ,, D A ,, C	$(l-2x)k$

Rule.—Find two results which add up to the same figure as a good core—in this case (1) and (2). Then the third reading will be obtained when one pair is made up of two wires that are crossed and the other pair of the two which are not crossed. (*Note.*—This third reading may be negative in sign, *i.e.*, the deflection "throw" will be in the opposite sense.)

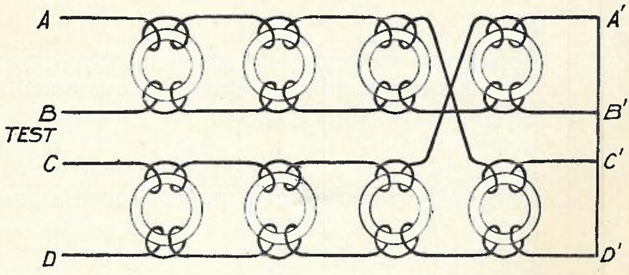


FIG. 19.

Taking the readings which add up to the normal figure of a good core and splitting the pairs at the testing end, each pair will contain a wire not crossed and one crossed. Unless it is specified which pair should be odd and even at the distant end it is not possible to say which of two wires have been crossed; for instance (See Fig. 19), take A, B, C and D at one end, coming out on A′, C′, B′ and D′—unless it is specified that A B should go to A′ B′ it is not possible to say whether A and C or B and D have been crossed and, moreover, the split may be removed by recrossing either of the two sets of wires mentioned. If, however, A B should go to A′ B′, the latter cross is the correct one to make to remove the fault. An example will perhaps make this clear :—

A B to A′ B′ and C D to C′ D′ at far end if correct.

A and C crossed. l equal 4 loading coils (side-circuit loading only).

Good core tested A C to B D : 19 divisions on Galvo.

Faulty Quad :	(1) A B to C D	and vice versa.	5 Divs.
	(2) A C to B D	,, ,,	9 ,,
	(3) A D to B C	,, ,,	14 ,,

Since 5 and 14 add up to 19 therefore A and C or B and

D are the crossed wires. (See Test (2)). Since C equals 4 and a " good " " throw " is 19, k is 19/4 or 4.75.

Hence from :

(1) $x = 5/4.75$ divisions, representing 1.05, say 1 coil.

(2) $(l - 2x) = 9/4.75$ divisions, representing 1.9, say, 2 coils.

(3) $(l - x) = 14/4.75$ divisions, representing 2.9, say, 3 coils.

Hence one coil has been split at the distant end.

If this split had been corrected by crossing B and D, the result would have been to cross A B, C D, and pairs between the two ends.

Example in method 1.

In the ordinary inductance test, if 24 had been the normal " throw " for a good loop, results as follows would be obtained : " good loop—A and C, A and D, B and C or B and D—13 divisions.

Faulty loops:

Across galvanometer and battery or *vice versa*:

A B and C D	21	divisions	"throw"	(1)
A C and B D	12	,,	,,	(2)
A D and B C	15	,,	,,	(3)

Since 6 divisions go to a good coil, 2 half coils give 3; hence for (1) one coil has been split, since (24-21) equals 3.

(64) *The Megger.*

The high range megger may be used for measuring the direct insulation between wires of a cable by the use of the guard terminal. See Fig. 20.

If the direct insulation between two wires A and B is required, A is joined to the "Line" terminal, and B to the "Earth" terminal; all the remaining wires of the cable and also earth being joined to "guard": alternatively, A and B may be interchanged.

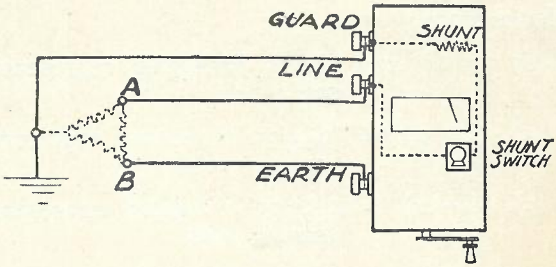


FIG. 20.

The high range megger may be converted to low range by shunting the guard and line terminals by a suitable resistance. If the high range megger is placed on a load of 10 megohms and a shunt is adjusted until the megger reads 1000 megohms, the reading of the megger with this resistance should be divided by 100 to give the insulation under test.

As the resistance in series with the megger is now lower, a long line may be more rapidly charged.

Fig. 21 shows a motor driven high range megger fitted with a switch to give two ranges.

Hence, in the new motor-driven meggers, the line may be charged by turning the switch to " Divide by 100 " and then, by turning the switch to " Divide by 1," allowing the needle to settle, a reading may more expeditiously be obtained.

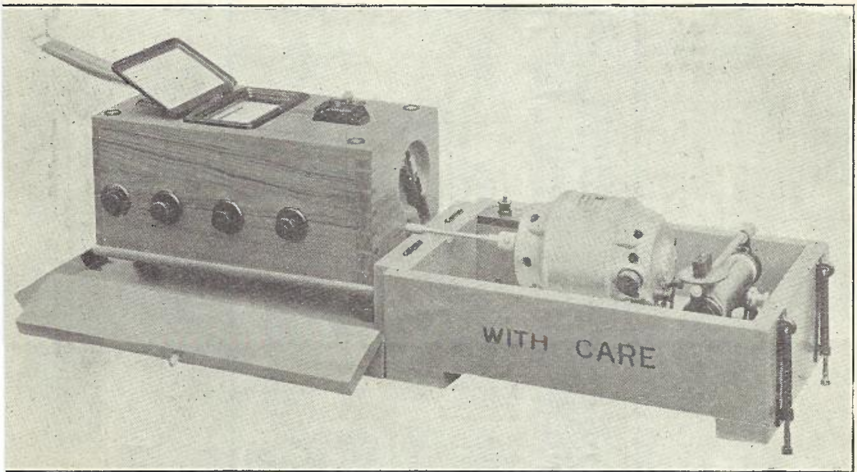


FIG. 21.

(65) *Error in Localisation Distance due to the Lumped Resistance of Loading Coils.*

An error is introduced when obtaining the distance to a fault by dividing the total loop resistance by the total distance. This error will vary from zero to a maximum (given in the table below) depending on the position of the fault in the loading section and the distance from the ends to the nearest coil. In no case can it be greater than the length of a loading section. The maximum error possible is the length of conductor loop which is equal in resistance to a loading coil (unit).

Conductor.	Loop Resistance per mile (approx.).	Coil Type 535. 135 *m*H. Resistance 3 ohms. Maximum error.		Coil Type 535 + 536. With phantom coil. Resistance 4 ohms. Maximum error.		Coil Type 584 + 583. With phantom coil. Resistance 10.4 ohms. Maximum error.	
		Miles.	Yards.	Miles.	Yards.	Miles.	Yards.
20 lb.	88 ohms.					0.118	208
40 ,,	44 ,,	0.0684	120			0.236	416
70 ,,	25 ,,	0.120	211			—	—
100 ,,	17.6 ,,	0.170	300	0.227	400	—	—
150 ,,	11.7 ,,	—	—	0.342	600	—	—
200 ,,	8.8 ,,	0.341	600	—	—	—	—

For other coils, divide the loop resistance of the coil by the resistance of a mile of cable.

APPENDIX VII.

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2.	do.	Vol. VII., 1915, page 110. "The Termination of Loaded Telephone Cables," by T. F. Purves.
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