SECTION 3

WHEATSTONE BRIDGE BG 1

The Wheatstone Bridge BG/1 was designed to permit the following types of measurement :—

(*a*) Resistance, e.g. Line loop.
(*b*) Resistance unbalance of lines by the Varley loop test.
(*c*) Internal resistance of batteries.

The bridge can be used for measuring resistances of any value up to 1·111 megohms to an accuracy above 100 ohms of one part in 10,000, and below 100 ohms to 0·01 ohm. Used as a resistance box the variable standard resistance enables any value between 1 and 11·11 kilohms to be obtained. The internal resistance of batteries, of voltages up to 200 volts, can be directly measured to within about 10 ohms.

Circuit Description (Fig. 2)

The resistances in the ratio arms of the bridge are controlled by rheostats designated *Multiply* and *Divide* respectively, located at the top of the panel on either side of the galvanometer. The switches each have three positions designated *10*, *100* and *1,000*, the designations indicating the value of resistance in circuit in ohms. The variable standard resistance is provided, like a resistance box, with four decade switches, one each for thousands of ohms, hundreds, tens and units. The galvanometer is a central-zero instrument reading up to 30 on either side. The battery and galvanometer keys are located at the bottom of the panel to the right of the centre and are of the push type. They are designated *B* and *G* respectively, and are each provided with a locking device. Three pairs of terminals are provided at the bottom of the panel on the left. The central pair, designated *X1* and *X2*, are for connecting the resistance or line to be measured and are extended to two jacks in the Test Bay jackfield, wired in parallel but with their tip and ring connections reversed so as to provide a ready means for reversing the line connections. The pair of terminals on the right, designated *R1* and *R2*, are connected directly across the four decade resistances and connection is made to them when it is desired to use them as a standard resistance box. The pair on the left, designated *B* — and *B* +, are provided for the connection of a battery of which the internal resistance is to be measured. The key in the centre of the panel has three positions. In the central position it arranges the circuit for simple resistance measurements and in the *Varley* position for measuring resistance unbalance. The third position is used in conjunction with the switch designated *Battery Only*, on the right of the panel, for arranging the circuit for the measurement of battery resistance. The latter key when operated substitutes equal resistances of fixed value, namely 2·5 kilohms and of adequate current-carrying capacity, in place of the variable resistances in the ratio arms, and also connects the resistance of the *Increase Sensitivity* control, located at the top right-hand corner of the panel, and a fixed resistance of 3 kilohms in series with the galvanometer.

A 6-volt d.c. supply is provided for the normal operation of the panel, either for the measurement of resistance or for the Varley test, and a 100-volt d.c. supply for battery-resistance measurements. Fuses are provided in the 100-volt positive lead and in the galvanometer circuit and are located on the back of the panel. Access to them is obtained by removing the back cover.

Measurement of Resistance (Fig. 3.1)

The resistance to be measured should be connected either to the *X1* and *X2* terminals or to one of the jacks in the Test Bay jackfield to which these are wired. The switches should be operated as follows :—

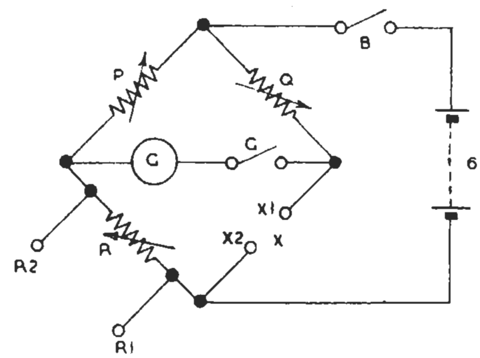

Fig. 3.1. Resistance Measurement Circuit

Varley-Batt Res key in *mid* position.
Battery only key to *off*.

The circuit is now arranged as a simple Wheatstone Bridge with the galvanometer connected, in series with its switch, between the junction of one of the ratio arms P and the variable resistance arm R and the junction of the other ratio arm Q and the unknown resistance arm X. The 6-volt battery, in series with its switch, is connected between the junction of P and Q and that of R and X. The variable resistance R is adjusted to a value such that when the battery and galvanometer keys are depressed there will be no current through the galvanometer. This condition obtains when the two ends of the galvanometer circuit are at the same potential, that is to say, when the ratio P/R is the same as the ratio Q/X. From this it follows that $X = R\frac{Q}{P}$

On the panel the variable resistances Q and P are designated *Multiply* and *Divide*, respectively. The rule therefore becomes $X = R\frac{\text{'Multiply' setting}}{\text{'Divide' setting}}$

The most sensitive condition is obtained when the resistances in the four arms of the bridge are all equal, or in practice, when the resistances in the ratio arms are equal to one another and of the same order as the resistance to be measured. Obviously, however, this condition can only be met for resistances which fall within the range of adjustment provided for the resistances in the ratio arms, namely between about 10 and 1 kilohm. Furthermore, it is only possible to equate the variable resistance R to the unknown resistance X over the range of adjustment provided for the former. Therefore, when the resistance to be measured exceeds 10 kilohms the unity ratio can no longer be used and Q must be made larger than P to enable a balance to be obtained, that is to say, the setting of the *Multiply* control must be greater than that of the *Divide* control. Likewise if the resistance to be measured is fairly small it will be impossible to obtain an exact balance with P and Q equal unless it is an exact number of ohms, because the fourth dial of the variable resistance does not give fractions of an ohm. In such a case therefore greater accuracy will be obtained if P is made greater than Q, that is to say, if the setting of the *Divide* control is greater than that of the *Multiply* control.

The foregoing remarks can be summarised in the following practical rules :—

(*a*) For resistances exceeding 10 kilohms, set *Multiply* to *1,000*, and set *Divide* to *100* if the resistance to be measured is less than 100 kilohms or to *10* if it is greater than 100 kilohms.

(*b*) For resistances between 100 and 10 kilohms set both *Divide* and *Multiply* controls to the same value, namely, *100* if the resistance to be measured lies between 100 and 500 ohms, and to *1.000* if it lies between 500 and 10 kilohms.

(*c*) For resistances under 100 ohms set *Multiply* to 10, and set *Divide* to *100* if the resistance to be measured is greater than 10 ohms or to *1.000* if it is less than 10 ohms.

Before making the test, the value of the resistance to be measured should be estimated and the decade dials initially set to the corresponding value. When making a test for balance the battery key *B* should always be depressed before the galvanometer key *G*, because otherwise, if the resistance under test has either an inductive or capacitative component the galvanometer needle will kick even in the balance condition. If when a test is made the needle deflects to the left, the resistance in circuit should be increased, and conversely, if the needle deflects to the right the resistance should be decreased.

Varley Loop Test

For measuring conductor resistance unbalance, the switches should be set as follows :—

Varley-Batt Res key to *Varley*.
Battery only key to *Off*.

The line to be tested should be connected either to the *X1* and *X2* terminals or to one of the

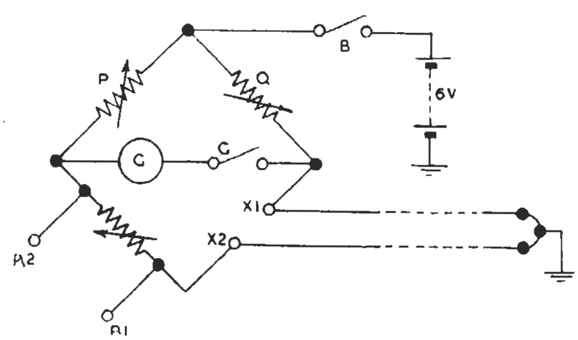

Fig. 3.2. Varley Loop Test Circuit

jacks in the Test Bay jackfield to which these are wired and at the distant station the conductors should be looped together and earthed.

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The circuit is now arranged as shown in Fig. 3.2, with the galvanometer connected as before in series with its key, between the junction of P and R and the junction of Q and X, and with the 6-volt battery connected in series with its key between the junction of P and Q and earth. The battery is thus virtually connected between the junction of the ratio arms and the earthed loop at the distant station so that the R arm of the bridge includes the variable resistance and one leg of the line, and the X arm the other leg of the line.

Unity ratio should be used, both the *Divide* and *Multiply* controls being set at *100*, and balance obtained as before by adjustment of the variable resistance. The test should be started with a resistance setting of zero, because if the two conductors have exactly the same resistance, balance will be obtained with the zero setting. If, however, the galvanometer shows a deflection this can be balanced out by inserting resistance in the R arm. If the deflection increases when resistance is inserted the line should be transferred to the other jack so as to reverse the connections to it. When balance is obtained, the resistance unbalance of the line is given directly by the setting of the decade controls.

In the event of two lines being looped A-A and B-B at the distant point, an overall test can be made by looping and earthing one of the lines and connecting the other to the Test jack. The result of the test in this case will be the algebraic sum of the unbalances of the two lines.

The Varley test can also be used for locating an earth on a line, but in this case the two legs of the circuit are looped only and not earthed at the distant point. The resistance of the loop should first be measured by the method described for resistance measurements, and then the resistance unbalance measured by the method given above. If *R1* is the loop resistance and *R2* the resistance unbalance, the distance of the earth in ohms from the station at which the measurement is made is then given by the expression $\frac{R1 - R2.}{2}$

Battery Resistance

For this measurement, the battery of which the internal resistance is required should be connected to terminals $B -$ and $B +$ in the correct polarity. The *Increase Sensitivity* control should be turned as far as possible in an anti-clockwise direction. The *Varley-Batt Res* key should be thrown to *Batt Res.* and the *Battery only* key to *On*.

The circuit is then arranged as shown in Fig. 3.3 The *Multiply* and *Divide* resistance in the ratio arms are cut out of circuit and fixed and equal resistances *P* connected in their places. The 100-

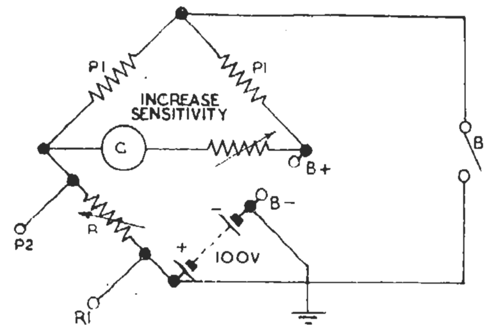

Fig. 3.3. Battery-resistance Measurement Circuit

volt battery is connected in the X arm in opposition to the battery to be tested, the negative poles of both batteries being earthed. The galvanometer is connected in series with a fixed resistance and with the *Increase Sensitivity* control between the junction of *P1* and R and the junction of *P1* and *X*, and the key *G* is no longer in circuit. The key *B* is connected across the junction of the two *P1* arms and that of the R and X arms, but the 6-volt battery is cut out of circuit, so that when this key is closed it merely places a short circuit across these two points. There will be a resultant e.m.f. due to the difference between the voltages of the two batteries, and this will cause a current to flow in either one direction or the other round the closed loop provided by the four arms of the bridge. A difference of potential will therefore exist between the ends of the high-resistance shunt containing the galvanometer and a deflection will be obtained. This is adjusted as nearly as possible to full scale deflection in order to obtain the most sensitive condition by means of the *Increase Sensitivity* control. If now the resistance in the R arm is adjusted to the same value as the resistance in the X arm, that is, if R is made equal to the internal resistance of the battery under test (the resistance of the 100-volt accumulator battery in series with it being negligible), it can be shown that placing a short-circuit across the points to which the contacts of the key *B* are connected will not alter the potential applied across the shunt containing the galvanometer.

If e is the resultant e.m.f., and if R = X then, neglecting the small current through the galvanometer, the current flowing round the loop with key B open, will be,

$$i_1 = \frac{e}{2(P1 + X)}$$

and the difference of potential across the shunt containing the galvanometer will be

$$2i_1 P1 \text{ which equals } \frac{eP1}{P1 + X}$$

If key B is now closed, the arm R and the left-hand arm $P1$ are short-circuited, and the potential at the left-hand end of the shunt containing the galvanometer is the same as that at the upper end of the right-hand arm $P1$. The current flowing round the loop will now be

$$i_2 = \frac{e}{P1 + X}$$

and the potential difference across the shunt containing the galvanometer will be

$$i_2 P1 \text{ which as before } = \frac{eP1}{P1 + X}$$

Having adjusted for approximately full-scale deflection by means of the *Increase Sensitivity* control, the process is therefore to adjust the variable resistance to a value such that when the key B is depressed no movement of the galvanometer needle can be detected. Over a wide range of adjustment of the decade dials the change in the meter reading will be extremely small, amounting to little more than a quiver, and unless the needle is closely observed when the key is actually being operated, it will be difficult to determine the point of balance with any degree of accuracy. In practice, however, results accurate to within about 10 ohms can be obtained with careful use.

If, with the *Increase Sensitivity* control set for minimum sensitivity, the galvanometer goes hard over against its stop, this will indicate that either the voltage of the 100-volt battery is low or that that of the battery under test is greater than 200. In the latter case the battery can either be tested in two sections or, if an accumulator of suitable voltage is available, this can be connected in series opposition with the battery under test in order to obtain a net voltage slightly less than 200. A similar expedient could be adopted in the unlikely case of the voltage of the battery under test being exactly the same as that of the test battery so that no galvanometer deflection is obtained. In this case, of course, it would not matter if the accumulator, which need only be about 2 volts, were connected in series opposition or in series aiding. In either case the error due to the small additional resistance introduced by the accumulator can be ignored.

Resistance Box

To use the decade resistances forming the variable resistance of the bridge as a resistance box it is only necessary to make connection to the terminals $R1$ and $R2$ and adjust the controls to the value required. Any exact number of ohms between 1 and 11,110 is available, but the current in the circuit should be restricted as follows :—

Units dial only in use ...	0·5 A
Tens and Units dials only in use	0·2 A
Hundreds, Tens and Units dials in use	60 mA
All dials in use	20 mA

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FIG 2 S4

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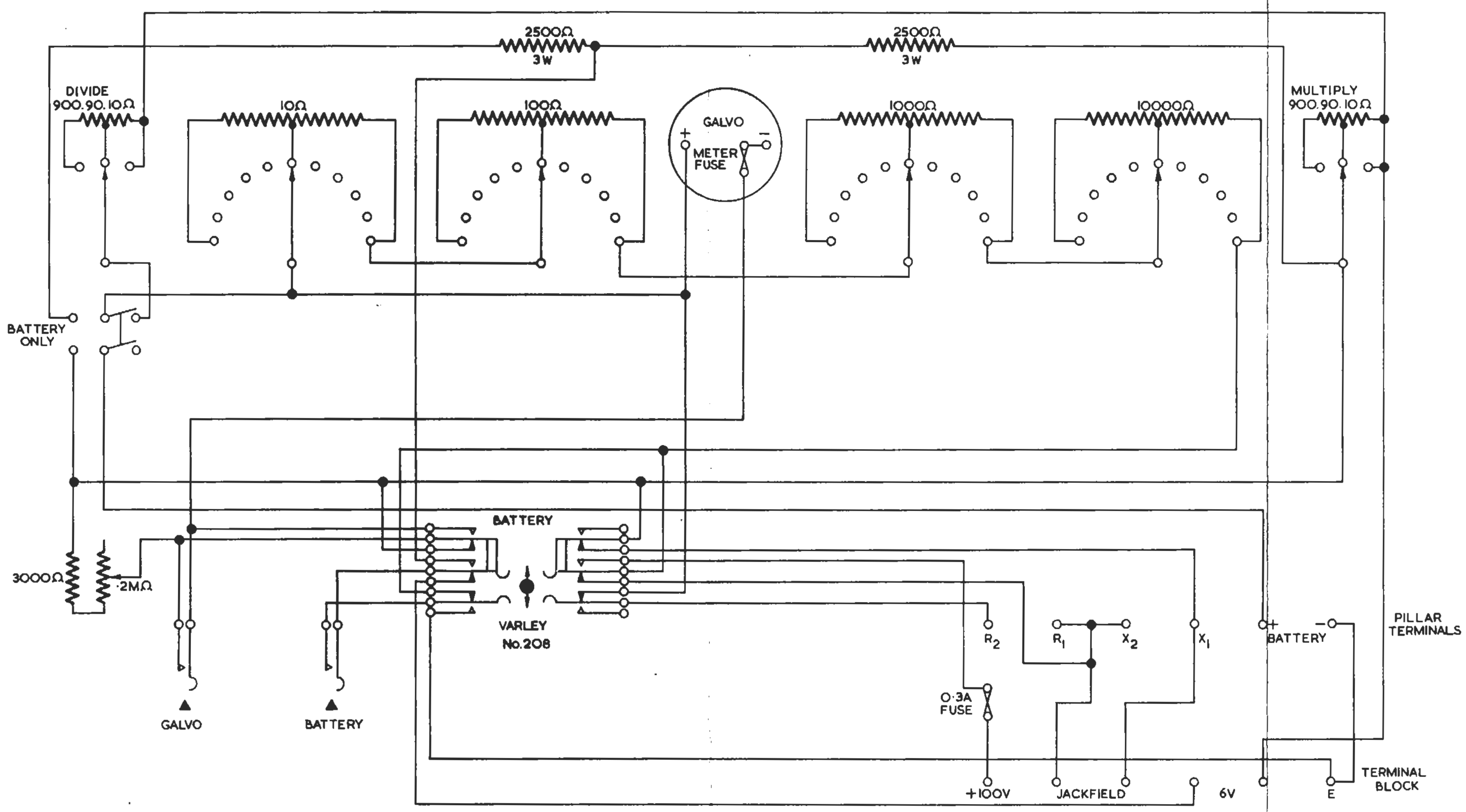

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