

July 19, 1949.

J. RAZEK

2,476,384

UNBALANCED BRIDGE COMPENSATION

Filed May 3, 1944

2 Sheets-Sheet 1

Fig. 1.

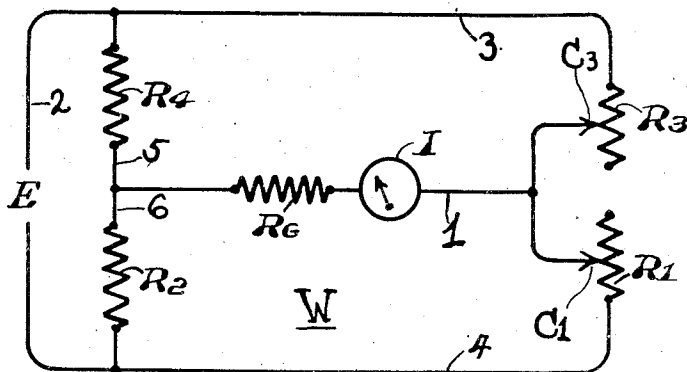


Fig. 2.

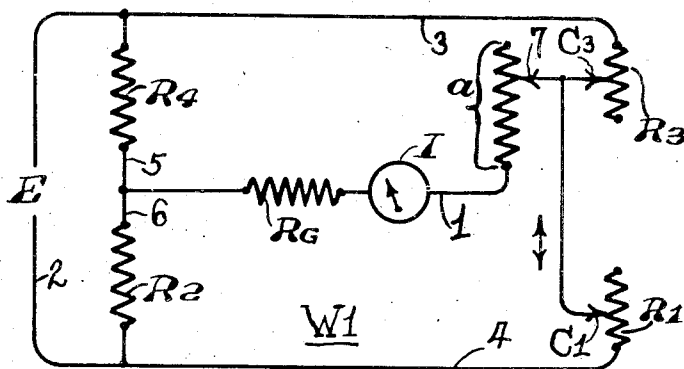
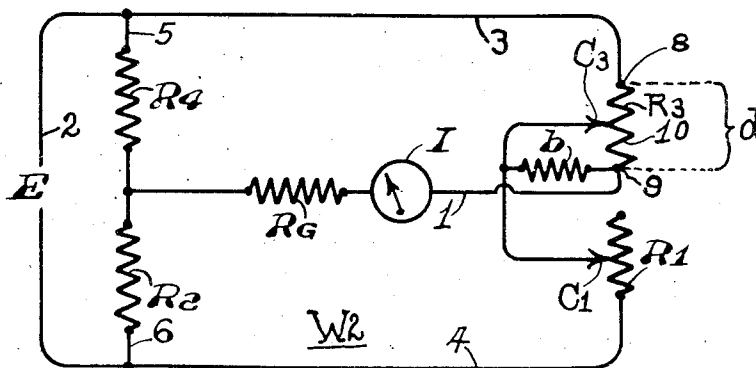


Fig. 3.



BY

INVENTOR
JOSEPH RAZEK
Co. L. Shret
ATTORNEY

July 19, 1949.

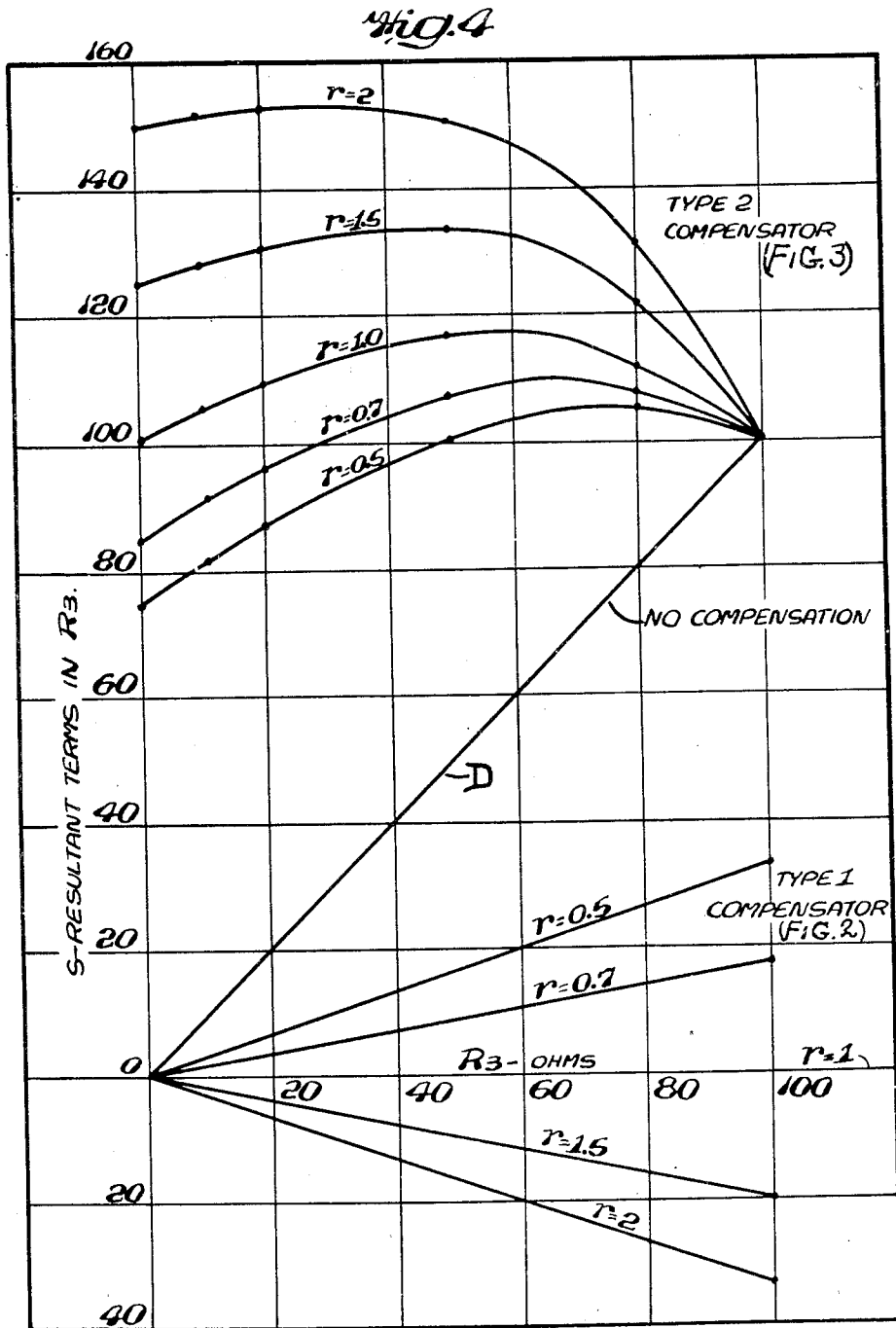
J. RAZEK

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2 Sheets-Sheet 2



INVENTOR

JOSEPH RAZEK

BY

C. L. Eshet

ATTORNEY

UNITED STATES PATENT OFFICE

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UNBALANCED BRIDGE COMPENSATION

Joseph Razek, Llanerch, Pa., assignor, by mesne assignments, to Cochrane Corporation, a corporation of Pennsylvania

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1 Claim. (Cl. 177—351)

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My invention relates to compensation for or reduction of errors, departures from perfect accuracy, occurring in connection with bridge networks, of the general character of that of Fig. 4 of my prior Patent 2,293,403, organized to measure, by measuring the current in a conjugate conductor of a bridge, the ratio to each other of the magnitudes of independently varied impedances in different arms of the bridge.

In accordance with my invention the contribution to such departure from perfect accuracy (in the representation of aforesaid ratio by the current aforesaid) as may be dependent upon or cause by either of aforesaid bridge-arm impedances is greatly reduced by compensation having the effect of varying the total impedance of that conjugate conductor of the bridge network which is traversed by the unbalance current representative of aforesaid ratio; more particularly the total impedance in the conjugate conductor is varied by providing therein an impedance whose effect varies in dependence upon the variation of the magnitude of one of aforesaid bridge-arm impedances; more specifically, the magnitude of the impedance in the conjugate conductor is increased as the magnitude of aforesaid one of the bridge-arm impedances decreases.

For illustration of some of the forms my invention may take, reference is to be had to the accompanying drawings, in which:

Fig. 1 is a diagram illustrative of a type of bridge to be compensated in accord with my invention;

Fig. 2 is a diagram of a bridge, generically the same as that of Fig. 1, modified to effect compensation;

Fig. 3 is a diagram illustrating a different species of compensation; and

Fig. 4 comprises characteristics illustrative of my invention.

Fig. 1, of character of that of Fig. 4 of aforesaid prior patent, is an unbalanced bridge-network W, in adjacent arms 3 and 4 of which are included independently variable portions, of impedances, including non-inductive resistances, R_3 and R_1 , representing, respectively, different concurrently varying magnitudes of different conditions, whose varying ratios are to be measured; in the other bridge arms 5 and 6 are respectively connected the impedances, such as non-inductive resistances, R_2 and R_4 ; in conjugate conductor 1, there is connected the deflect-

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ing current meter I whose impedance or resistance and that of the remainder of the conjugate conductor is indicated at R_g ; in the other conjugate conductor 2 is connected a source of current E; all in accord with aforesaid patent.

The relations between the current ig in conjugate conductor 1, the various impedances and the voltage of source E are those of Equation 1, as follows:

$$ig \left[R_g(R_2 + R_4) \left(1 + \frac{R_3}{R_1} \right) + R_2 R_4 \left(1 + \frac{R_3}{R_1} \right) + R_3(R_2 + R_4) \right] = E \left[R_2 \left(\frac{R_3}{R_1} \right) - R_4 \right]$$

This equation is the one appearing in aforesaid patent, and for present purposes may be rewritten as Equation 2, as follows:

$$ig \left[R_g(1+r) + \frac{R_2 R_4}{R_2 + R_4} (1+r) + R_3 \right] = E \left[\frac{R_2 r - R_4}{R_2 + R_4} \right]$$

in which r represents the ratio, represented by the current ig passed through current-measuring deflection instrument I, of concurrent magnitudes of impedances R_3 and R_1 .

In Equation 2 the current ig is a function only of the ratio r and of the fixed impedances or resistances R_2 and R_4 , except for the single term R_3 , in the coefficient of ig . The current ig will not be an exact measure of the ratio r , because of or owing to the presence in such coefficient of the term R_3 ; such error, for different magnitudes of impedance R_3 , rapidly diminishes with decrease from maximum of the magnitude of R_3 . As stated in aforesaid patent, such error may be minimized by choosing for impedances or resistances R_g , R_2 and R_4 fixed magnitudes which are high as compared with any possible magnitudes of the variable impedance R_3 . Such remedy (which, if desired, may be used also in applying this invention) has disadvantages which do not arise in accordance with my present invention.

The broad aspect of my present invention is the inclusion in conjugate conductor 1 of an impedance, such as a resistance, in series with galvanometer or current meter I, which is decreased in magnitude, as the magnitude or resistance of impedance R_3 increases, to extent causing aforesaid effect of resistance R_3 to be very materially reduced; which is indicated by Equation 2.

One species of aforesaid solution is effected, as indicated by Fig. 2, by including a variable portion of an impedance or resistance a in series in conjugate conductor 1; the amount of resistance a in series in conjugate conductor 1 is increased as the amount of resistance R_3 , i. e. kR_3 , in bridge-arm 3 diminishes. The contact C3, which varies resistance R_3 , and the contact 1, which

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varies resistance a , are preferably moved in unison and electrically connected to each other, and both are connected to contact C1 which varies resistance R1 in bridge-arm 4; contacts 7 and C3 constitute a terminal of conjugate conductor 1. Accordingly as resistance R3 increases the resistance a decreases; and if both resistance R3 and a are linear, in the sense that equal adjustments of contacts C3 and 7 effect equal changes in resistance of a and R3 respectively in conjugate conductor 1 and bridge-arm 3, and taking the magnitude of the resistance a , for any magnitude of resistance R3, remaining in series in conjugate conductor 1, as $a = kR3$, Equation 2 may be written as Equation 3, as follows:

$$ig \left[\left(Rg + a + \frac{R2R4}{R2+R4} \right) (1+r) + \frac{R3(c-r)}{c+1} \right] = \frac{E(R2r-R4)}{R2+R4}$$

in which a is the maximum magnitude of resistance a , and k is equal to

$$\frac{1}{1+c}$$

of which c is that magnitude of the ratio to each other of resistances R3 and R1 at which the effect of R3 is completely eliminated; c generally is taken as the magnitude of aforesaid ratio r occurring at the midpoint of the range of the possible magnitudes of r . Accordingly it is possible to determine from Equation 3 that magnitude of the auxiliary resistance a which will render the effect of resistance R3 as small as possible.

Another species for the same generic purpose, which in construction is even simpler than that of Fig. 2 in that the compensating impedance element or resistor in the conjugate conductor need not itself be variable, is shown in Fig. 3. That impedance, b , which may be of fixed magnitude as shown, is in series in conjugate conductor 1 whose terminal is contact C3 which, as in Fig. 2, varies that part of impedance or resistor R3 which is in bridge-arm 3 to different magnitudes representative, for example, of various magnitudes of a condition. As that portion of resistor R3 in arm 3 is varied by movement of contact C3 there is complementally varied that portion 10 of impedance or resistor R3 external to arm 3 and in parallel with impedance or resistor b , so varying the impedance or resistance effectively in series in conductor 1, and so rendering the current therein of magnitudes much more accurately representative of the ratio to each of the magnitudes of the portions of impedances R3 and R1 concurrently in bridge arms 3 and 4, respectively. In brief, as the impedance in arm 3 increases, the impedance of the couple, b and 10 in parallel with each other and in series in conjugate conductor 1, decreases.

Taking the maximum impedance of R3, between points 8 and 9, as d , the impedance in series in conductor 1 in shunt to b is $d-R3$. Therefore, for any magnitude of R3 in Equation 2 above, there is in series with all other impedances in conductor 1 an impedance of magnitude

$$\frac{b(d-R3)}{d+b-R3}$$

and when in the same equation for Rg is substituted

$$Rg + \frac{b(d-R3)}{d+b-R3}$$

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the relation applicable to Fig. 3 becomes Equation 4:

$$ig \left[\left[Rg + \frac{R2R4}{R2+R4} + \frac{b(d-R3)}{d+b-R3} \right] (1+r) + R3 \right] = \frac{E(R2r-R4)}{R2+R4}$$

By way of example only, for purposes of discussion, in Figs. 1, 2 and 3 Rg may be 200 ohms, and R3, maximum, may be 100 ohms; and in Fig. 3, b , maximum, may be 100 ohms, and the resistance, maximum, of 10 may be 100 ohms.

Letting S represent that part of the coefficient of ig which is a function of R3, there may be written, with respect to Fig. 2, Equation 5, as follows:

$$S = R3 \cdot \left(\frac{c-r}{c+1} \right)$$

and with respect to Fig. 3 there may then also correspondingly be written, Equation 6, as follows:

$$S = \frac{db(1+r) + R3(d-br) - (R3)^2}{d+b-R3}$$

and, for simplicity, taking the magnitude of resistance b as equal to the maximum magnitude of resistance R3, which is indicated as d , Equation 6 may be written as Equation 7, following:

$$S = \frac{d^2(1+r) + dR3(1-r) - (R3)^2}{2d-R3}$$

The characteristics and effectiveness of the compensating methods and apparatus herein described may well be shown by assuming numerical magnitudes. For example, it being assumed the maximum magnitude of R3 is 100 ohms, and calculating the magnitudes of S from foregoing Equations 5-7 for various cases, and recalling that the current ig , measured by the instrument I in conjugate conductor 1, represents r , the ratio of resistance R3 to resistance R1, it is apparent current ig must be a function of r and fixed magnitudes only; or otherwise stating it, ig may not be a function of either R1 or R3 alone. Consequently it is best that ig be a function of r and terms which are nearly constant. If S were constant for all magnitudes of R3 alone, compensation would be perfect regardless of the various different magnitudes R3 might take. Failing such relation, it is desirable S be as nearly constant as possible for all magnitudes of R3 at any given magnitude of the ratio r . Which is to say, S need not in fact be constant for all magnitudes of R3, because it only is essential that S vary or change as slowly as possible as R3 changes in magnitude. Whatever the magnitude of S , which may be designated as the error term, for various magnitudes of ratio r may be, they are taken care of in the permanent calibration of the scale of the meter I, and since that scale is not in any case linear, there results no substantial harm, for S itself is a function of r . Differently stated, S should vary as slowly as possible with variation of R3, and a more rapid variation of S with respect to r is of no particular significance or consequence.

Taking the foregoing into consideration, reference may be had to Fig. 4, which by graphs illustrates the characteristics and behaviors of the types of compensator herein described.

The straight line characteristic D represents a plot of the equation $S=R3$, from which it follows aforesaid error term S is equal to the mag-

nitude of R_3 , which is the case when no compensation is effected.

However the magnitudes of S for various magnitudes of R_3 and various magnitudes of r , for the system of Fig. 2, are shown by the series of straight line characteristics extending from the origin O to the right; that the effect of R_3 , as an error term, is very greatly reduced, never approaching a magnitude greater than one-third of the magnitude of R_3 , even for a range of magnitudes of ratios r as great as .5 to 2.0 which range is actually larger than the range of the magnitudes of ratio r usually met with or used in commercial applications of my invention.

The family of characteristic curves, the upper portion of Fig. 4, relate to Fig. 3. Here the magnitude of the error term S varies only a little more, and the maximum variations of S correspond with the small magnitudes of R_3 . From these characteristics it is seen the compensating effect in accordance with Fig. 2 is greater for the lower ranges of the magnitudes of R_3 , while on the other hand, respecting Fig. 3, the compensation is more effective for the higher magnitudes of R_3 . In practice, however, there is no great difference between the types of compensation of Figs. 2 and 3, though, in the case of Fig. 3, its greater structural or mechanical simplicity may render it preferable to that of Fig. 2.

In any case, however, it is seen either type of compensation very greatly reduces the error contributed or caused by the R_3 term, so that its effect never will or need be more than one or two percent; and even so it is possible still further to reduce or minimize the error to any extent desired by choosing for R_g a sufficiently high magnitude. For example, if the S term should vary to an extent such as 50 ohms, the resulting error may be diminished to any desired percentage or magnitude by making R_g sufficiently large. By recourse to either of the herein described types of compensation the amount by which R_g must be increased to confine the error to a particular magnitude, is reduced by a factor or from about 3 to about 5, depending upon the range of operation, or the extent of range of the magnitudes of ratio r , for which the compensating system is designed.

It is noted, with respect to Fig. 4, the principle employed for illustrating effectiveness of the compensation is not predicated upon or does not take into account the collaterally helpful fact that as the bridge approaches a balance, any error whatever remaining is eliminated, with the consequence the effect of aforesaid error terms upon the position of the deflecting pointer of instrument I actually will be much less than may appear at first glance in Fig. 4.

Accordingly both types of compensation herein described make possible great reduction in such error, as may be occasioned by either R_1 or R_3

of Fig. 1, by correlating with either one of them means for increasing the impedance in conjugate conductor I to extents suitably related, either broadly, or specifically in accord with foregoing Equations 3 and 4, to the decreases in magnitude of the impedance of that portion of element R_3 (or R_1) which is in bridge-arm 3 (or 4), thereby greatly increasing the fidelity or accuracy with which the magnitudes of the current through conductor I truly represent the ratios to each other of the various magnitudes of the separately or independently varied impedances R_1 and R_3 .

An aspect of my invention resides in the fact aforesaid results are obtainable without sacrifice of the generally desirable conditions that the total impedance in the conjugate conductor I and/or impedances R_2 and R_4 be not so great as to enforce use of a source E of correspondingly higher voltage, and that employment of a current meter I of much higher sensitivity is avoidable.

As between Figs. 2 and 3, the latter is the simpler from the viewpoint of structural characteristics in that although impedance b is or need not itself be variable, its effect nevertheless is suitably varied to extent and in sense by adjustment of the same contact, C_3 , which is essential to variation of the amount of impedance element R_3 which shall be included in bridge-arm 3 in accord with the fundamental principle exemplified by Fig. 1.

What I claim is:

A bridge comprising a pair of fixed impedances having a junction point, a pair of independently variable impedances having a junction point, the outer terminals of said pair of fixed impedances being connected to the respective outer terminals of said pair of variable impedances, means for applying an energizing potential to said outer terminals of the pairs of impedances, means connecting said junction points including a meter for measuring unbalance current flow between said junction points and a variable impedance in series with said meter, and means for concurrently varying the last mentioned variable impedance and one of the first mentioned variable impedances in opposite senses to maintain relatively independent of variations of the first mentioned variable impedances the accuracy of measurement by said meter of the ratio of values of the first mentioned variable impedances.

JOSEPH RAZEK.

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