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AUTOMATIC BALANCING ARRANGEMENT

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This invention relates to electrical testing and signaling systems and more particularly to means for automatically preserving the balance of an electrical network such as for instance a Wheatstone bridge, said network being capable of being used for any of a variety of purposes.

While this invention is shown and described in one particular embodiment merely for the purpose of illustration, it will be understood that this invention may be applied to other and widely varied organizations without departing from the spirit of the invention or the scope of the appended claims.

In accordance with this invention in the embodiment here described for the purpose of illustration, a Wheatstone bridge arrangement is kept in a balanced condition through the agency of apparatus principally comprised of a reversible driving motor and means for controlling the motor consisting of differentially connected gas-filled trigger type tubes fed by an amplifier if the tubes themselves are insufficiently sensitive. Two general arrangements are described: One in which the balancing is done in steps of predetermined size, and another where the apparatus is sensitive to any small changes and will remain closely balanced.

The invention may be more fully understood from the following description together with the accompanying drawing in the Figures 1 and 2 of which the invention is illustrated. Fig. 1 is a circuit diagram showing a preferred form of the invention. Fig. 2 is a circuit diagram showing the invention in modified form. Similar reference characters have been used to denote like parts in both of the figures.

With particular reference to Figs. 1 and 2, resistances A and B form the ratio arms of a Wheatstone bridge. In this particular example the resistance to be balanced consists of a line L and a fixed resistance D in parallel therewith, such an arrangement as might be encountered for instance in connection with a pilot wire regulator system for use in connection with telephone repeater systems. Since the variation in this combination is usually small the primary balance is secured by a fixed resistance R and the final balance by a potentiometer, X—Y, with X in series with R and with Y in series with L and D. A battery B₁, and a protective resistance P, comprise one diagonal of the bridge, and the other diagonal is led off through a network comprising resistances S₁ and S₂ and condenser C₁ to an amplifier of the direct type.

The amplifier may be of the single tube or

push-pull type. A push-pull amplifier is shown in Fig. 1. It comprises the vacuum tubes T₃ and T₄. Tube T₃ has a grid 11, a cathode 12, and a plate 13. Tube T₄ has a grid 16, a cathode 15, and a plate 14. The filament battery is 19, and the plate battery is 20. Current limiting resistances 17 and 18 are shown in the input circuits of the tubes. The operation of an amplifier of this type is well known in the art. In the output circuit of tube T₃ is the resistance M. In the output circuit of tube T₄ is the resistance N. A gas-filled discharge tube T₁ has its electrodes connected across resistance M. In order to provide a biasing potential for the tube T₁, a battery B₂ and a potentiometer O are provided. A gas-filled discharge tube T₂ has its electrodes connected across resistance N. In order to provide a biasing potential for the tube T₂, the battery B₂ and the potentiometer Q are provided. The gas-filled tubes T₁ and T₂ might, for example, have a gaseous content such as neon or argon.

As heretofore pointed out, the network comprising resistances S₁, S₂ and condenser C₁ is connected across diagonally opposite points of the Wheatstone bridge. If the bridge is balanced there will be no potential difference across the plates of condenser C₁, and the potential on the grids of tubes T₃ and T₄ will be the same. Accordingly, the currents in the plate circuits of the tubes T₃ and T₄ will be equal, and the voltage drops across M and across N will be equal. If the Wheatstone bridge now becomes unbalanced due, for example, to a change in resistance of L, there will be a difference in potential across C₁ and different potentials will be applied to the grids of the tubes T₃ and T₄. This will cause a difference in the current flow in the plate circuits of the tubes T₃ and T₄, and hence the voltage drop across resistance M will be different from the voltage drop across resistance N. It will thus be seen that if the bridge becomes unbalanced that the voltage across the electrodes of the gas-filled discharge tubes T₁ and T₂ will be varied. This effect may be utilized in a manner to be pointed out in more detail hereinafter to cause either of the gas-filled tubes to operate. The operation of either of the tubes will operate relay mechanism to drive the motor 21 in the proper direction to cause the potentiometer switch 22 to rebalance the Wheatstone bridge.

In the push-pull type amplifier of Fig. 1 there will be no potential across C₁ when the Wheatstone bridge is balanced and under such conditions there will be equal and opposite potentials across resistances M and N. If the bridge be-

comes unbalanced and a potential of a certain polarity is impressed across C_1 , the drop across M will be increased and that across N will be decreased. If the bridge becomes unbalanced in the other direction and a potential of the opposite polarity is impressed across C_1 , the drop across M will be decreased and the drop across N will be increased. As heretofore pointed out, the battery B_2 and resistances O and Q provide a potentiometer arrangement for setting the biasing potentials of tubes T_1 and T_2 . In general, B_2 should be of the order of or larger than the potential required to operate either of the tubes T_1 or T_2 . It is then possible to adjust the potentials on T_1 and T_2 , which are for T_1 the sum of the drops across the part of resistance O in use and the resistance M, and for T_2 the sum of the drops across the part of resistance Q in use and the resistance N added algebraically. For example, assuming that tubes T_1 and T_2 each operates at a potential of 115 volts and that with no potential across C_1 there is a drop across M and N each of 10 volts in such a direction that the potential in each of the tubes is 10 volts plus 100 volts derived from the potentiometers O and Q, or normally 110 volts each. Separate adjustment is provided in order to make it possible to compensate for small individual variations in the tubes.

Assuming then that a potential due to unbalance of the Wheatstone bridge is impressed across C_1 of the proper polarity and magnitude to cause the drop across M to be changed from 10 volts to 15 volts and across N from 10 volts to 5 volts, the potential across tube T_1 will be 115 volts and the tube T_1 will operate. The potential across tube T_2 will be reduced to 105 volts. For an equal potential of opposite polarity due to unbalance of the bridge in the opposite direction, the situation will be reversed and tube T_2 will be operated.

For an amplifier not of the push-pull type such, for example, as amplifier T_5 of Fig. 2, a similar set of conditions can be originated except that where the drops across M and N are each normally 10 volts with no potential impressed across C_1 , a potential due to unbalance of the bridge of a given size and polarity might cause each of the potentials across M and N to increase to 15 volts, and an equal and opposite polarity would cause the potentials across M and N each to decrease to 5 volts. In order to secure operation of tube T_1 in the first case, i. e., 15 volts across M and 15 volts across N, and of tube T_2 in the second case, i. e., 5 volts across M and 5 volts across N, it is necessary to consider the polarity of these voltages and to arrange the bias potentials supplied by O and Q accordingly. For instance, if the bias potential supplied by O is 100 volts and that supplied by Q is 120 volts, the potential normally across tube T_1 would be $100+10$, or 110 volts, and that across T_2 $120-10$, or 110 volts, with no potential impressed across C_1 . With a potential across C_1 so that the drops across M and N are each 15 volts, the potential across T_1 will be $100+15$ and T_1 will operate. The potential across T_2 would be $120-15$, or 105 volts. For an equal and opposite potential across C_1 causing potentials across M and N of 5 volts each, the potential across T_1 would be $100+5$, or 105 volts, and that across T_2 would be $120-5$, or 115 volts, and T_2 would operate. Thus it is seen that the same purpose can be obtained with different kinds of amplifiers, said amplifiers being multi-stage if desired. In an A. C. system, the use of

an amplifier-detector would be possible to supply the necessary drops across M and N. The use of gas-filled tubes for T_1 and T_2 having grids, does not alter the sense of the invention but merely changes the value and arrangement of the bias potentials.

The operation of tubes T_1 and T_2 is arranged to operate relays R_1 and R_2 , respectively, from the discharge current. Due to the inherent nature of the gas-filled tubes they will, for the conditions outlined, remain operated, since, in general, the release potential is very much lower than the firing potential and may be, for example, in the case noted, of the order of 70 volts. It is necessary then, in order to release tubes T_1 and T_2 and their associated relays R_1 and R_2 , to reduce the potential sufficiently or open the circuit, which function is accomplished by contacts of relay R_3 when the occasion arises.

The operation of relay R_1 will close the following circuit; from ground, armature and contact of R_1 , conductor 23, winding of relay R_3 , to battery B_5 and ground. This will operate relay R_3 which will pull up its armature and close the following circuit; from ground, contact and armature of relay R_3 , conductor 24, winding of relay R_7 , to battery B_4 and ground. This will operate relay R_7 which will pull up its armature and close the following circuit; from the positive side of battery B_3 , contact and armature of relay R_7 , conductor 25, armature winding of motor 21, conductor 26, to the negative side of battery B_3 . The operation of relay R_7 will also close the following circuit; from the positive side of battery B_3 , contact and armature of relay R_7 , conductor 25, contact 27 and armature 29 of relay R_6 , conductor 30, field winding of motor 21, conductor 31, armature 40 and contact 32 of relay R_6 , conductor 26, to the negative side of battery B_3 . Thus it will be seen that when the gas-filled tube T_1 operates and causes the operation of relays R_1 , R_3 and R_7 , that the current flow through the field winding of the motor 21 will be in a certain direction, as, for example, from conductor 30 to conductor 31. This will cause the motor to rotate the shaft 7 in a certain direction and operate the switch 22 in the proper direction to reduce the unbalance potential of the Wheatstone bridge which caused T_1 to operate. The operation of relay R_2 will close the following circuit; from ground, armature and contact of relay R_2 , conductor 35, winding of relay R_4 , conductor 36, to battery B_5 and ground. This will operate relay R_4 which will pull up its armature and close the following circuit; from ground, contact and armature of relay R_4 , conductor 37, winding of relay R_6 , conductor 38, to battery B_4 and ground. This will operate relay R_6 which will pull up its upper armature and close the following circuit; from ground, upper armature and contact of relay R_6 , conductor 34, winding of relay R_7 , to battery B_4 and ground. This will operate relay R_7 which in the same manner will apply current from battery B_3 to the armature winding of motor 21. Due to the fact that relay R_6 is now operated, the operation of relay R_7 will now cause current from battery B_3 to be applied to the field winding of motor 21 in the following manner: from the positive side of battery B_3 , contact and armature of relay R_7 , conductor 25, contact 28 and armature 40 of relay R_6 , conductor 31, field winding of motor 21, conductor 30, armature 29 and contact 33 of relay R_6 , to the negative side of battery B_4 . In other words, when relays R_2 , R_4 , R_6 and R_7 are operated, the current flow through the

field winding of motor 21 will be the reverse from that heretofore described in connection with the operation of relays R_1 , R_3 and R_7 . Accordingly, the motor will operate the shaft 7 in the opposite direction and thus operate switch 22 in the proper direction to reduce the unbalance potential of the Wheatstone bridge which caused T_2 to operate.

The differences between Figs. 1 and 2 will now be pointed out.

In Fig. 1, which is so arranged as to balance the bridge in steps of predetermined amount, the driving motor, acting through a gear reducer device 41, controls a shaft 7, which operates the balancing potentiometer $X-Y$, and has attached to it a toothed wheel 1 engaging a roller 2, carried by arm 3, supported by fulcrum 4, and engaging contacts 5 and 6. Normally, when the bridge is in the balanced condition, roller 2 is in a depression of wheel 1, and arm 3 is engaged with contact 5, condenser C_2 is connected to the winding of relay R_5 and is in the discharged condition. R_5 is, accordingly, in the non-operated position.

Assume an unbalance potential to be impressed across C_1 , as described above, sufficient to cause tubes T_1 or T_2 to fire, operating relays R_1 or R_2 , and later relays R_3 or R_4 , and causing the driving motor to rotate in one direction or the other, shaft 7 and the associated wheel 1 and potentiometer $X-Y$, to rotate in one direction or the other, depending upon the polarity of the unbalance potential across C_1 . Tubes T_1 or T_2 will remain broken down and the aforesaid operation will continue, roller 2 being raised from a depression of wheel 1 until arm 3 makes engagement with contact 6, charging condenser C_2 to the potential of battery B_6 . Wheel 1 will continue to rotate until roller 2 again approaches a depression, whereupon arm 3 again makes engagement with contact 5, discharging condenser C_2 through the winding of relay R_5 , and momentarily operating relay R_5 .

The momentary operation of relay R_5 opens the circuit 42 supplying battery for the potentiometers O and Q and permits the tubes T_1 or T_2 to be extinguished, releasing the associated relays R_1 and R_2 and subsequently R_3 or R_4 , and stopping thereby the action of the driving motor and its associated train, shaft 7, wheel 1, and potentiometer $X-Y$.

During the aforesaid operation in which wheel 1 has been advanced one tooth in one direction or the other, and its associated potentiometer $X-Y$ changed a corresponding amount, the balance of the bridge has been corrected by this said amount. It may be that this said amount of correction is sufficient so that upon restoral of battery to tubes T_1 and T_2 by the restoral of relay R_5 the unbalance potential across C_1 will be insufficient to cause tubes T_1 or T_2 to fire and, accordingly, the arrangement remains quiescent until such time as the unbalance across C_1 shall have increased to a sufficient amount to cause tubes T_1 or T_2 to fire. If, however, one step has been insufficient to reduce the unbalance potential to the point where tubes T_1 or T_2 will not fire, tubes T_1 or T_2 will fire a second time and the action described above will be repeated until a sufficient number of steps has been made to render the unbalance potential across C_1 too small to fire T_1 or T_2 . It should be borne in mind that the margin of operation should be such that the apparatus will not hunt, i. e., step too far and step

back, repeatedly oscillating, unless this condition is desired.

The shaft 7 can be extended to control resistances in other circuits, or to do any useful work which might ordinarily be accomplished by controlled rotary motion.

The action of the arrangements of Fig. 2 is substantially similar to that of Fig. 1. The toothed wheel and its associated apparatus are removed and relay R_5 , controlling the circuit 42 supplying potential to T_1 and T_2 , is associated with another relay R_8 in such a way that when R_3 or R_4 has operated, for reasons noted above, and the balance is being adjusted through changes in potentiometer $X-Y$, relay R_5 repeatedly operates at close intervals under control of relay R_8 in the following manner: Relays R_3 and R_4 are each provided with two armatures and two contacts. When either of these relays operate the following circuit will be closed; from ground and over a contact and armature of either relay R_3 or R_4 , to conductor 43, and thence through the winding of relay R_5 , contact and armature of relay R_8 to battery B_7 and ground. This will cause the operation of relay R_5 which will pull up its armature and open circuit 42 supplying potential from battery B_2 to the tube T_1 and T_2 and cause these tubes to be extinguished. The operation of relay R_5 will cause it to close its left-hand armature and contact and close the following circuit; from ground and battery B_7 , winding of relay R_8 , armature and left-hand contact of relay R_5 , and thence over conductor 43 to ground by way of an armature and contact of either relay R_3 or R_4 . It is pointed out that these latter relays are slow releasing and will remain operated for an interval after tubes T_1 and T_2 are extinguished. The operation of relay R_8 will open the circuit for relay R_5 and cause it to release. The release of R_5 will cause relay R_8 to release. The release of R_8 will again close a circuit for R_5 and cause it to operate again as long as R_3 or R_4 are operated. This cycle of events will continue as long as either R_3 or R_4 are operated. With each operation of R_5 , battery B_2 is removed from potentiometer O and Q and consequently from tubes T_1 and T_2 permitting their release and the release of R_1 and R_2 . Restoral of R_5 restores the battery B_2 to the tubes T_1 and T_2 and permits one of them to operate again in case the unbalance potential has been insufficiently reduced. This release and operation will continue until the unbalance potential is reduced sufficiently so that tube T_1 and T_2 will not operate. Relays R_3 and R_4 should preferably be of the slow release type so that their operation will hold over momentary releases of R_1 and R_2 , but will release when T_1 or T_2 refuses to operate again upon restoral of battery B_2 .

As in the case of Fig. 1, shaft 7 can be utilized for any useful control purpose.

While the invention has been disclosed as embodied in certain specific arrangements which are deemed desirable, it is understood that it is capable of embodiment in many and other widely varied forms without departing from the spirit of the invention as defined by the appended claims.

What is claimed is:

1. A Wheatstone bridge, a potentiometer included in one of the ratio arms of said bridge, a circuit connected across diagonally opposite points of said bridge, two resistance elements connected in said circuit, two gas-filled discharge tubes having their cathode-anode circuits connected across said resistances, the circuits of said tubes and the values of said resistances being so

proportioned and adjusted that when said bridge is balanced said tubes will be in a non-discharging condition and when said bridge is unbalanced either of said tubes will discharge, means controlled by the operation of either of said tubes for varying the setting of said potentiometer to restore the balance of said bridge, and means controlled by the operation of either of said tubes for restoring the tubes to a non-operative condition.

2. A Wheatstone bridge, a potentiometer included in one of the ratio arms of said bridge, a circuit connected across diagonally opposite points of said bridge, an amplifier included in said circuit, two resistance elements included in the output circuit of said amplifier, two gas-filled discharge tubes having their cathode-anode circuits connected differentially with respect to each other across said resistances, each of said resistances and each of said cathode-anode circuits being so adjusted that when said bridge is unbalanced in one respect the voltage drop across one of said resistances will cause the operation of one of said tubes and when said bridge is unbalanced in another respect the voltage drop across the other of said resistances will cause the operation of the other of said tubes, means controlled by the operation of said gas-filled discharge tubes for changing the setting of said potentiometer to restore said bridge to a balanced condition, and means controlled by the operation of either of said tubes for restoring the tubes to a non-operative condition.

3. A Wheatstone bridge, a potentiometer included in one of the ratio arms of said bridge, a circuit connected across diagonally opposite points of said bridge, an amplifier included in said circuit, two resistance elements included in the output circuit of said amplifier, two gas-filled discharge tubes having their cathode-anode circuits connected differentially with respect to each other across said resistances, each of said resistances and each of said cathode-anode circuits being so adjusted that when said bridge is unbalanced in one respect the voltage drop across one of said resistances will cause the operation of one of said tubes and when said bridge is unbalanced in another respect the voltage drop across the other of said resistances will cause the operation of the other of said tubes, means controlled by the operation of said gas-filled discharge tubes for changing the setting of said potentiometer to restore said bridge to a balanced condition, and means controlled by the operation of said last mentioned means for intermittently opening the cathode-anode circuits of said gas-filled discharge tubes.

4. A Wheatstone bridge, a potentiometer included in one of the ratio arms of said bridge, a circuit connected across diagonally opposite points of said bridge, an amplifier included in said circuit, two resistance elements included in the output circuit of said amplifier, two gas-filled discharge tubes having their cathode-anode circuits connected differentially with respect to each

other across said resistances, each of said resistances and each of said cathode-anode circuits being so adjusted that when said bridge is unbalanced in one respect the voltage drop across one of said resistances will cause the operation of one of said tubes and when said bridge is unbalanced in another respect the voltage drop across the other of said resistances will cause the operation of the other of said tubes, means controlled by the operation of said gas-filled discharge tubes for changing the setting of said potentiometer in a step-by-step manner to restore said bridge to a balanced condition, and means controlled by the operation of said last mentioned means and operating for each step that said potentiometer setting is changed for momentarily opening the cathode-anode circuits of said tubes.

5. A Wheatstone bridge, a potentiometer included in one of the ratio arms of said bridge, a circuit connected across diagonally opposite points of said bridge, an amplifier included in said circuit, two resistance elements included in the output circuit of said amplifier, two gas-filled discharge tubes having their cathode-anode circuits connected differentially with respect to each other across said resistances, each of said resistances and each of said cathode-anode circuits being so adjusted that when said bridge is unbalanced in one respect the voltage drop across one of said resistances will cause the operation of one of said tubes and when said bridge is unbalanced in another respect the voltage drop across the other of said resistances will cause the operation of the other of said tubes, relay means controlled by the operation of one of said tubes, relay means controlled by the operation of the other of said tubes, a motor, means controlled by said motor for changing the setting of said potentiometer, means controlled by one of said relay means for operating said motor in one direction, means controlled by the other of said relay means for operating said motor in another direction, and means controlled by either of said relay means for restoring the tubes to a non-operative condition.

6. A Wheatstone bridge, a circuit connected across diagonally opposite points of said bridge, a push-pull amplifier in said circuit, resistances in the plate circuit of said push-pull amplifier, two gas-filled discharge tubes connected across said resistances, one of said tubes being adjusted to operate on the voltage drop through its associated resistance when said bridge becomes unbalanced in one respect, the other of said tubes being adjusted to operate on the voltage drop through its associated resistance when said bridge becomes unbalanced in the opposite respect, means controlled by the operation of each of said tubes for restoring said bridge to a balanced condition, and means controlled by each of said tubes for restoring the tubes to a non-operative condition.

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