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ELECTRICAL CALCULATING APPARATUS

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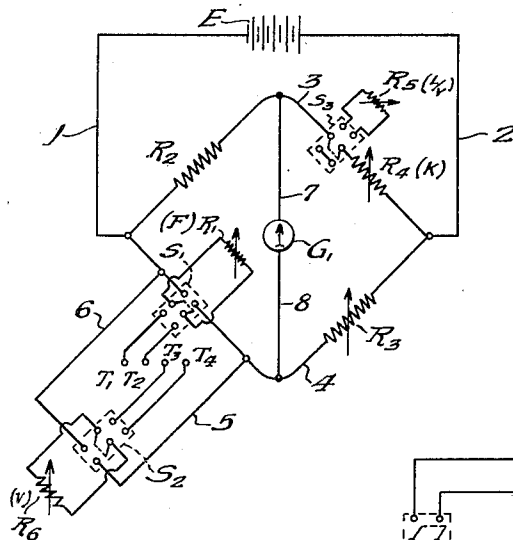


Fig. 1.

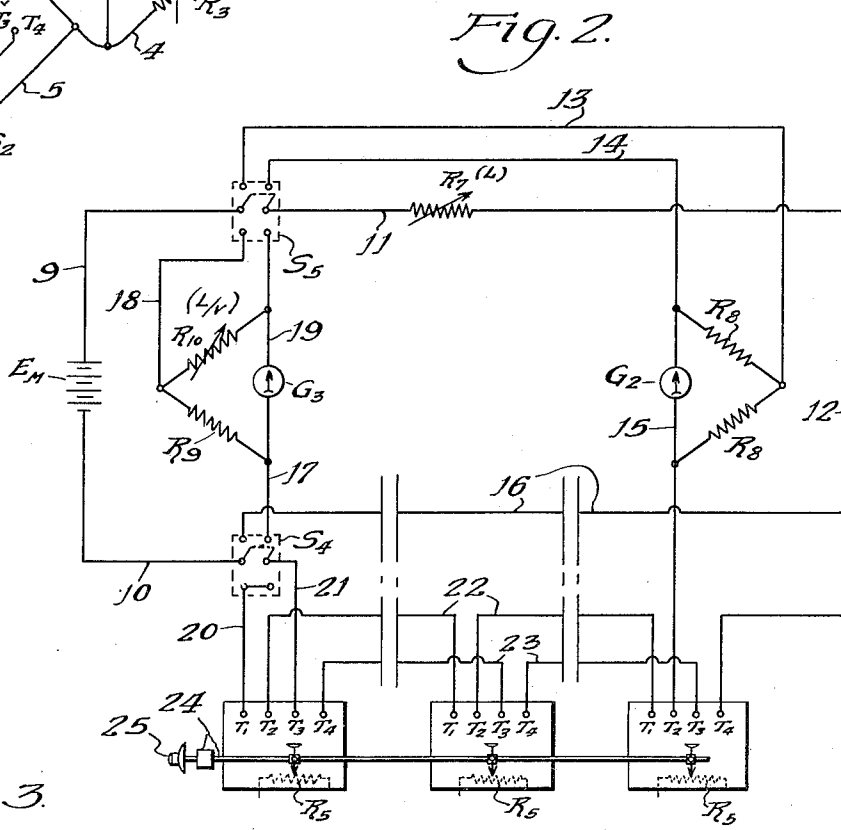
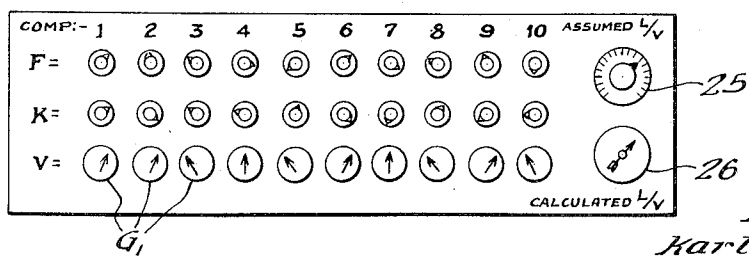


Fig. 2.

Fig. 3.



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ELECTRICAL CALCULATING APPARATUS

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4 Claims. (Cl. 235—61)

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This invention relates to a method and apparatus for solving trial and error type of calculations by electrical means, or more specifically, carrying out addition, subtraction, multiplication and division by use of a system of electrical resistance circuits of the Wheatstone bridge type.

The calculating machine of this invention, in any particular embodiment, must be designed to solve one particular type of equation, as for example the equation:

$$V = \frac{F_1 K_1}{(L/V) + K_1} + \frac{F_2 K_2}{(L/V) + K_2} + \dots$$

In this equation, which relates to liquid and vapor phase separation in a multicomponent phase separation system, the value of V is commonly found by a series of trial and error calculations. The above equation is familiar to process engineers, as it is used in the design of separating or fractionating systems wherein the L/V value, or equilibrium relationship between liquids and vapors, must be found. In the phase separation of a petroleum feed stock, having several different components, the trial and error determination of equilibrium conditions may become very laborious.

In the above formula, for determining an equilibrium vaporization of a mixture; V equals the total number of mols of gas produced which contains $V_1 + V_2 + V_3 + \dots$ mols of the several components, while a total liquid residue of L mols remains which contains $L_1 + L_2 + L_3 + \dots$ mols of the several liquid components. In carrying out a process design, and in making separation calculations, the L/V ratio is estimated while the temperature and pressure conditions are known along with the number of mols of composition of the total feed F , which in turn is composed of fractions $F_1 + F_2 + F_3 + \dots$. The K values $K_1, K_2, K_3, \dots$, being the equilibrium constants for each of the components, are also known from the design conditions, or more specifically, may be picked from suitable equilibrium constant charts or tables.

The present invention is explained and described in connection with the above equation, however, other equations of a similar type may be calculated in the same manner with the machine calibrated to suit the particular equation. The apparatus makes use of a number of electrical resistance circuits, one circuit for each component of the phase separation system and a master circuit to which each of the component circuits is connected. All circuits have variable resistances and switching means placed such that

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each circuit may be balanced individually as well as the entire system balanced, in order to determine the correct and desired value of L/V . The L/V value is the ratio of total liquid phase to total vapor phase and is initially estimated or assumed in order to solve a trial and error calculation or equation, of the type mentioned above.

Briefly, the operation of this invention comprises the following steps, with the calculating apparatus carrying out the computations in the following manner: (1) the equation

$$\frac{FK}{(L/V) + K}$$

is solved for each component of the multicomponent phase separation with the values of $F_1, F_2, F_3, \dots, K_1, K_2, K_3, \dots$, and L/V being inserted into the machine by means of adjustable calibrated variable resistances and the value of $V_1, V_2, \dots$ effected for each component equation by means of each component circuit of the system. (2) The separate values of $V_1, V_2, V_3, \dots$ are added to give a total V . (3) The values of $F_1, F_2, \dots$ are added to give a total F . (4) The subtraction of $F - V$ is effected to give L and the ratio L/V obtained and indicated. (5) The L/V value determined in the previous step is compared to the originally assumed L/V and is then either varied by hand or by suitable automatic mechanisms in the calculating machine until the determined and assumed L/V values are identical.

A particular advantage of this calculating machine is that the determination of an unknown value may be accomplished accurately and far more quickly by the calculator than can be carried out by laborious long hand calculations, as is usually necessary in equations of the type indicated.

The accompanying drawing and following description thereof will serve to clarify the construction and arrangement of the electrical circuits as well as explain the operation of the machine.

Figure 1 of the drawing shows diagrammatically an individual electrical circuit which is provided and adjusted for each component of a multicomponent system.

Figure 2 illustrates diagrammatically a master electrical circuit with three individual component circuits being indicated in combination with the master circuit. More than three circuits may of course be used in the calculating machine, so that the latter will have an individual circuit for

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each component of any feed stock that may be subjected to phase separation.

Figure 3 of the drawing illustrates one possible arrangement of a control board for the calculating machine of this invention, with provision being made for solving a 10 component equation.

The electrical resistance circuit of Figure 1 will solve one equation of the type

$$\frac{FK}{(L/V)+K}$$

This circuit is repeated in the machine so that a circuit is available for each component of a phase separation system. All component circuits in the apparatus are identical in principle although they may or may not have the same resistance values. Referring now to the drawing, a direct current potential E is connected with a Wheatstone bridge circuit by means of wires 1 and 2. The Wheatstone bridge circuit divides into two branches 3 and 4, branch 3 has resistances R_2 , R_4 and R_5 , while the other, branch 4, has resistances R_1 , R_3 and R_6 . A double-pole double throw switch S_1 serves to cut the variable resistance R_1 into the bridge circuit or to connect the terminals T_1 and T_2 with the resistance R_1 . Double-pole double throw switch S_2 connecting to branch 4 by means of wires 5 and 6, serves to cut in the variable resistance R_6 or to connect the latter with the terminals T_3 and T_4 while the double-pole double throw switch S_3 serves to cut or to bypass the variable resistance R_5 with branch 3 of the electrical circuit. A galvanometer G_1 , is connected between the two branches of the circuit 3 and 4 by means of wires 7 and 8 so that the circuit may be brought into balance. The galvanometer G_1 is preferably of the type that has zero at the center and a plus or minus deviation indicated at either side of the center such that the instrument will aid in bringing the circuit into balance. The switches in the circuit are indicated to be of the double-pole double throw manually operated type, however, this is done principally for illustrative purposes, as it is quite possible to employ automatic switches or relays of mechanical or electronic type in the circuit to effect the necessary cutting in and out of resistances. Terminals T_1 and T_2 connect with switch S_1 while terminals T_3 and T_4 connect with switch S_2 . Thus, terminals are provided to connect the individual circuits into a master circuit, as will be hereinafter described.

In operation, the electrical resistance circuit of Figure 1 calculates one of the separate component equations

$$\frac{FK}{(L/V)+K}$$

This circuit will be reproduced as many times in the calculating apparatus as may be desired, in order to be able to include all components of the vapor-liquid phase separation system. In making calculations of petroleum systems, 15 circuits should be sufficient, however, as previously noted there is theoretically no limit to the number of separate circuits which may be integrated to make a calculating machine. The value of L/V is assumed and is set on the calibrated variable resistance R_5 . The known values of F and K for any one component are also set into the circuit, with the variable resistance R_1 being adjusted to the value of the number of mols of component F and the variable resistance R_4 adjusted to correspond to the K value, or equilibrium constant, for the given component. The double-pole double throw switch S_1 is set to tie resistance R_1 (the F value) into the circuit.

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Switch S_2 is set to tie resistance R_6 (the V value) to the terminals T_3 and T_4 , thus eliminating it from the circuit, while the switch S_3 is also set to by-pass the resistance R_5 from the circuit in the first balancing operation. The variable resistance R_3 is then adjusted until the galvanometer G_1 shows no deflection and the Wheatstone bridge circuit is in balance, with

$$R_3 = \frac{R_1 R_4}{R_2} \text{ or } R_3 = \frac{FK}{R_2}$$

This relation may be shown as follows:

i_1 = current in branch 3

i_2 = current in branch 4

$$i_1 R_2 = i_2 R_1$$

$$i_1 R_4 = i_2 R_3$$

$$i/i_2 = R_1/R_2$$

and

$$i/i_2 = R_3/R_4$$

therefore,

$$R_1/R_2 = R_3/R_4$$

and

$$R_3 = \frac{R_1 R_4}{R_2} \text{ or } \frac{FK}{R_2}$$

In the next operating step the switch S_3 is set to tie R_5 (the assumed L/V value) into series with R_4 the switch S_2 is set to bring R_6 into the circuit and the switch S_1 is set to tie R_1 to terminals T_1 and T_2 . The variable resistance R_6 may then be adjusted until the galvanometer G_1 indicates zero deflection and a balanced circuit is achieved whereby

$$R_6 = V = \frac{FK}{(L/V)+K}$$

This may be demonstrated as follows:

i_1 = current in branch 3

i_2 = current in branch 4

$$i_1 R_6 = i_2 R_2, \text{ and } \frac{i_2}{i_1} = \frac{R_6}{R_2}$$

$$i_1 R_3 = i_2 (R_4 + R_5), \text{ and } \frac{i_2}{i_1} = \frac{R_3}{R_4 + R_5}$$

By substitution,

$$\frac{R_6}{R_2} = \frac{R_3}{R_4 + R_5}, \text{ and } R_6 = \frac{R_3 R_2}{R_4 + R_5} = \frac{FK}{(L/V)+K} = V$$

It may thus be seen that the resistance circuit of Figure 1 provides a method to multiply, add and divide in solving a given equation, the solution being effected by the use of calibrated variable resistances in a Wheatstone bridge or balancing type of circuit.

The electrical system of Figure 2 includes a master circuit in combination with a series of the component circuits, such as were described in Figure 1, whereby there may be solved this form of equation:

$$V = \frac{F_1 K_1}{(L/V)+K_1} + \frac{F_2 K_2}{(L/V)+K_2} + \dots$$

In Figure 2, the terminals T_1 , T_2 , T_3 , and T_4 are shown, indicating three different component circuits such as in Figure 1. Of course, more than three circuits may be incorporated in the calculating machine of this invention, its operation being the same, regardless of the number of component circuits therein. A direct current source E_m is connected between double-pole, double throw switches S_4 and S_5 by means of wires 9 and 10. A variable resistance R_7 , which reaches the value of L , or the total number of

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mols of the liquid components, is connected with S_5 by wire 11, and to terminal T_4 of one of the end circuits, by wire 12. The fixed resistances R_8 are necessary to complete a Wheatstone bridge circuit and are connected to one side of the double-pole, double throw switch S_5 by wires 13 and 14. The resistances R_8 also connect to a galvanometer G_2 by means of the wire 14 and lead 15. The lead 15 also ties galvanometer G_2 with terminal T_2 of one of the end circuits of the component circuits. The wire 16 connects with one side of double-pole, double throw switch S_4 and ties potential E_m with wire 12, which joins resistance R_7 and terminal T_4 , the latter in turn tying in the sum of the R_6 resistances of the component circuits. The fixed resistance R_9 connects with switch S_4 and a galvanometer or current indicating device G_3 , by means of wire 17, and junctions with the variable resistance R_{10} and S_5 by means of wire 18. The variable resistance R_{10} in operation reaches a value proportional to L/V , or the ratio of total liquid phase to total vapor phase for the entire vapor-liquid phase separation. The variable resistance R_{10} connects with galvanometer G_3 and one side of the switch S_5 by means of wire 19. The double-pole, double throw switch S_5 in turn operates either to tie one side of R_{10} to R_7 and to tie the potential E_m with junction between R_9 and R_{10} or to tie R_7 to the junction of R_8 and G_2 and to tie E_m to the junction of the two like resistances R_8 . The double-pole, double throw switch S_4 , when thrown to the lower set of poles indicated, ties the terminals T_1 and T_3 together by wires 20 and 21 and simultaneously joins the potential E_m to the junction between them. The connecting wires 22 and 23 serve to tie the various component circuits together in series.

The current indicators or galvanometers G_2 and G_3 , like the ones G_1 of each component circuit, are preferably of a type that have the zero point at the center line and indicate plus and minus deviations either way from the center line. A central control mechanism 24 with dial 25 is also provided to adjust simultaneously each variable resistance R_5 of each component circuit to the same value.

In Figure 3 of the drawing there is shown one possible form of the control board of the calculating machine. Vertical columns of dials and indicators are arranged to accommodate each component of a separation system, the columns being numbered from 1 to 10 such that 10 components in the feed stock may be accommodated in the embodiment shown. The upper row of dials F provides means to adjust variable resistances R_1 to a value equal or proportional to the number mols of each component. The row of adjustable dials K provides means for setting each variable resistance R_4 to a value equal or proportional to the equilibrium constant for each of the components. The lower row of indicators V provide a value for the solution of each component equation

$$\frac{FK}{(L/V)+K}$$

The indicators V , of course, measure in terms of electrical resistance, but may have calibrated dials to indicate a mathematical value. The upper right hand dial marked L/V is the dial 25 of Figure 2 and is used to set all variable resistances R_5 to the ratio which is initially assumed. The indicator L/V in the lower right hand corner,

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and numbered 26, measures in terms of electrical resistance and is calibrated to provide the calculated final value of L/V , and in a correct solution of the equation this final value of L/V on indicator 26 must read the same value as the dial setting of the above L/V , dial 25, with all circuits being in balance.

In operating the master circuit, the following steps are carried out: The component circuits are first brought into balance with the L/V value which has been assumed and the $V_1, V_2, V_3, \dots$ value found for each component. The switches S_2 are set to tie the various R_6 values into the main circuit through terminals T_3 and T_4 . The switches S_1 are thrown to connect with T_1 and T_2 when bringing each separate component circuit into a final balance, thus resistances R_1 are brought into the master circuit with the R_6 resistances, with each being thereby eliminated from the component circuits. The switch S_4 of the master circuit is first actuated to tie terminals T_1 with terminals T_3 so that there is a summation of component F resistances to give a total F and a summation of component V measurements in series to provide a total V . The switch S_5 is first set to tie the potential E_m to the junction of the fixed resistances R_8 and R_7 to the junction of the resistance R_9 and the galvanometer G_2 . The variable resistance R_7 is adjusted until galvanometer G_2 indicates zero deflection, so that R_7 is made to equal L , or a value equal to the total number of mols of liquid phase of the separation system, i. e., $L=F-V$. The Wheatstone bridge circuit which provides this value is made up of the sum of R_1 resistances, or F , and one fixed resistance R_8 on one side, while the sum of the R_6 resistances, or V , the resistance R_7 and the other fixed resistance R_8 are on the other side. Thus in balance, $FR=(V+R_7)R_8$ since $R_8=R_8$, and $R_7=F-V=L$, as stated above.

With L determined, the double-throw switch S_4 is actuated to tie R_9 and G_3 with the terminal T_3 and the potential E_m with wire 12, the latter in turn junctions the variable resistance R_7 with terminal T_4 of the end component circuit. The double-throw switch S_5 is moved to tie R_7 , by way of wire 19, to the junction of G_3 and the variable resistance R_{10} , as well as connect the potential E_m to the junction of R_9 and R_{10} . The variable resistance R_{10} is then adjusted until the galvanometer G_3 shows zero deflection, thereby effecting a balanced circuit and making R_{10} proportional to L/V . This L/V proportional value of R_{10} is connected with the indicator arm of the calibrated measuring device 26, the latter being mounted on the control board of the machine as indicated in Figure 3. When the equation is properly balanced, the values of dial 25 and the indicator 26 are exactly in agreement.

The proof of variable resistance R_{10} being proportional to L/V may be demonstrated at follows: A Wheatstone bridge circuit exists in the master circuit with R_7 and R_{10} on one side and R_8 and R_9 on the other.

i_5 =current in one side of balanced circuit

i_6 =current in other side of balanced circuit

$$i_5 R_7 = i_6 R_8; \frac{i_5}{i_6} = \frac{R_8}{R_7}$$

$$i_5 R_{10} = i_6 R_9; \frac{i_5}{i_6} = \frac{R_9}{R_{10}}$$

$$\text{Thus, } \frac{R_8}{R_7} = \frac{R_9}{R_{10}} \text{ and } R_{10} = \frac{R_9 R_7}{R_8}$$

and by substitution $R_{10}=R_9(L/V)$. Since R_9 is a constant, R_{10} is directly proportional to L/V and the indicator 26 may be calibrated in terms L/V .

The form of the improved calculator machine and its operation has been set forth indicating manual switching and manual balancing of all circuits. This has been done however, to clarify the operating steps. In actual practice, the machine may be switched and balanced automatically thereby simplifying the steps to be handled by the operator and to effect also a "speeding up" of the solution of the problem. All switching may be handled by a mechanical or electronic mechanism that would operate them in a proper sequence, and at the proper time. In like manner, all balancing may be done either electronically or mechanically with a master control to operate the balancing resistance in the proper sequence and with the galvanometers being replaced by balancing mechanisms which would be tied to the variable resistances that in turn make each bridge circuit a balanced circuit. Also, the mechanisms could be arranged, so that if the final machine calculated L/V did not agree with the assumed value of L/V , the assumed L/V would be varied by suitable mechanical means, and all operations repeated to give a new value of L/V , this value compared with the newly assumed L/V , another adjustment made if necessary and so on until the assumed L/V and L/V calculated did agree.

It may be further noted, that A. C. current can be substituted for the direct current power source indicated. Alternating current would of course require suitable combination of capacitances, inductances, and resistances to provide a balancing impedance circuit of the Wheatstone bridge type.

From the foregoing description, it may be seen that the method and apparatus provided by this invention, operates to add, subtract, multiply and divided by means of electrical resistance circuits and thereby solves equations, which normally may be solved only by trial and error calculations.

I claim as my invention:

1. A calculating machine for solving equations of the type

$$V = \frac{FK}{(L/V) + K}$$

which comprises a balancing type electrical resistance circuit, a fixed resistance and two variable resistances in one branch of said circuit, three variable resistances in the other branch of said circuit, with one of said variable resistances in one arm of last said branch and two variable resistances in the other arm thereof, an electric potential connected to said circuit, a current indicating device connected across said circuit, means to switch one of the variable resistances of first said branch in and out of said circuit, multiple switching means and terminal connections connected in the last said branch of said circuit, with last said multiple switching means arranged to connect two of the three variable resistances of last said branch alternatively within said circuit and with said terminal connections, said balancing circuit operative to multiply, add and divide resistances and thereby effect the desired value of V .

2. A calculating machine for solving mathematical linear equations wherein it is necessary to multiply, add and divide to effect a solution, said machine comprising in combination a Wheatstone bridge type of electrical resistance

circuit, a fixed resistance and two variable resistances in one branch of said circuit, three variable resistances in the other branch of said circuit with one of said variable resistances in one arm of last said branch and two variable resistances in the other arm thereof, an electric potential connecting to said circuit, a current indicator connecting across said circuit from one branch to the other, calibrated adjustment dials connecting with the two variable resistances in first said branch and one of said variable resistances of second said branch of said circuit, a switch in first said branch positioned to cut one of said variable resistances in and out of said branch, further switching means and terminal connections in the other of said branches of said circuit with last said switching means arranged to connect two of said three variable resistances of last said branch alternatively within said circuit and said terminal connections.

3. A calculating machine for solving mathematical equations of the type

$$V = \frac{F_1 K_1}{(L/V) + K_1} + \frac{F_2 K_2}{(L/V) + K_2} + \dots$$

wherein total $F=L+V$ and L and V are unknown, said machine comprising in combination a plurality of Wheatstone bridge type of electrical resistance circuits connected in series and a master electrical resistance circuit connected with said plurality of circuits, each of said plurality of Wheatstone bridge type of circuits having five variable resistances and one fixed resistance, two variable and one fixed resistance in one branch and three variable resistances in the other branch of each of said circuits, a substantially constant electric potential connecting to the junction of each branch of said plurality of circuits, a current indicating device connected across said branches, a switch in first said branch positioned to cut in and out thereof one of said variable resistances, multiple switching means and two pairs of terminals in the other branch of said circuit, said multiple switching means connecting with two of said three variable resistances and operative to replace one of said variable resistances for the other of said variable resistances in last said branch and to connect the resistance being replaced in said circuit with a pair of said terminals, each pair of said terminals of said plurality of circuits connecting to said master circuit, two variable resistances and three fixed resistances connected in combination with said plurality of Wheatstone bridge circuits in said master circuit, a constant voltage potential, two current indicating devices, and additional switching means within said master circuit, one switch of last said additional switching means connecting the master circuit with all of said terminals of said plurality of circuits, a second switch of last multiple switching means connecting on one positioning to said master circuit to cut out one of said variable resistances and one of said fixed resistances of said master circuit whereby the remaining resistances of said circuit form a balanceable circuit therein with the resistances of the plurality of circuits in series therewith and provide thereby an L value for said equation, said first switch of said additional switching means of said master circuit operative in an alternative position to eliminate one series of resistances from said plurality of circuits with said second switch operative to replace said previously cut out variable and fixed resistances whereby a second balanceable bridge type of circuit is made within

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said master circuit and the L/V ratio determined.

4. The apparatus of claim 3 further characterized in that each branch of each of said plurality of Wheatstone bridge circuits have calibrated dials connecting with one of said variable resistances, a central control dial and an inner-connecting mechanism operates each variable resistance of first said branch of each plurality of circuits which is cut in and out of said circuit, whereby said resistances may be mechanically adjusted to the same value in each of said plurality of circuits, and a second calibrated control dial connects with the last mentioned variable

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resistance of said master circuit which is adjusted to balance said master circuit and provide a calculated L/V ratio.

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