

Jan. 20, 1942.

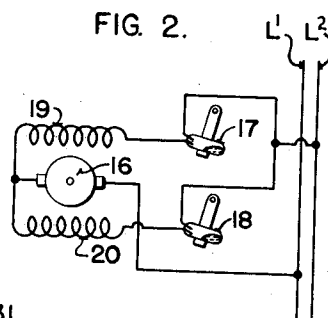
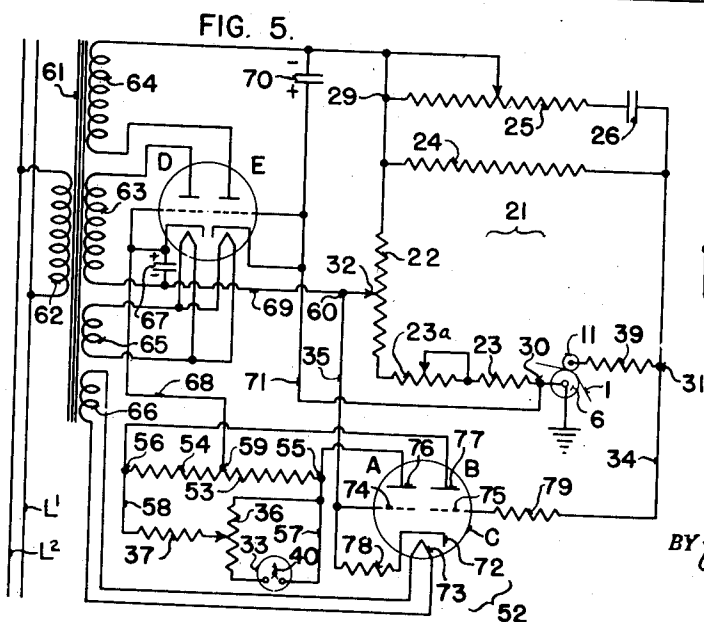
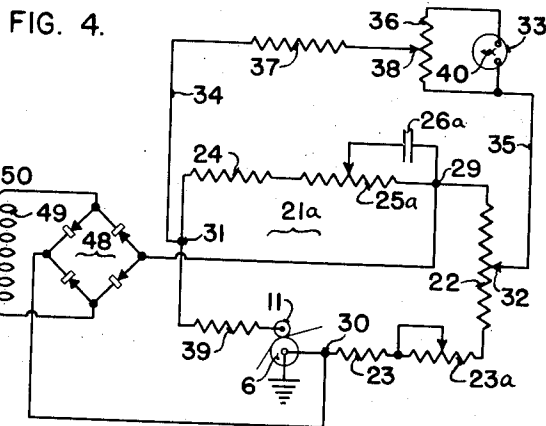
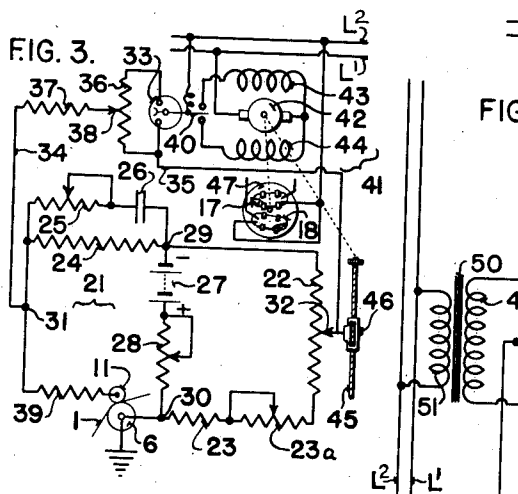
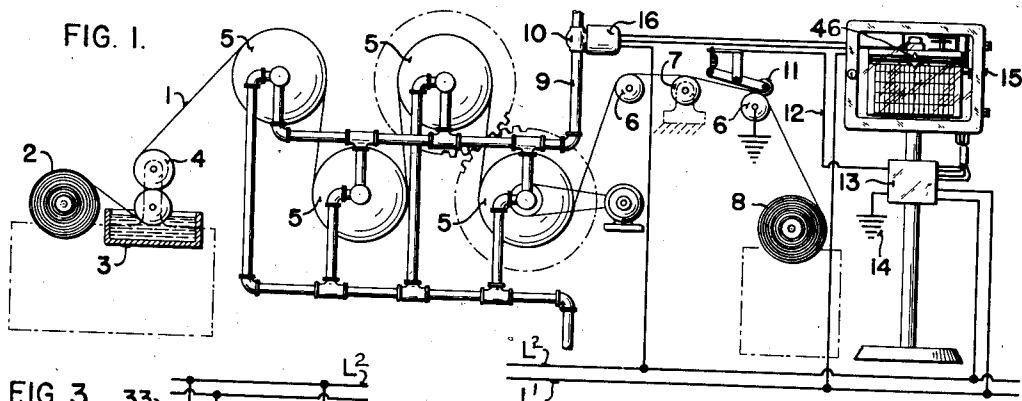
H. S. JONES

2,270,732

MEASURING AND CONTROL APPARATUS

Filed May 22, 1940

2 Sheets-Sheet 1



INVENTOR.
HARRY S. JONES
BY *E. B. Shannberg*
ATTORNEY.

Jan. 20, 1942.

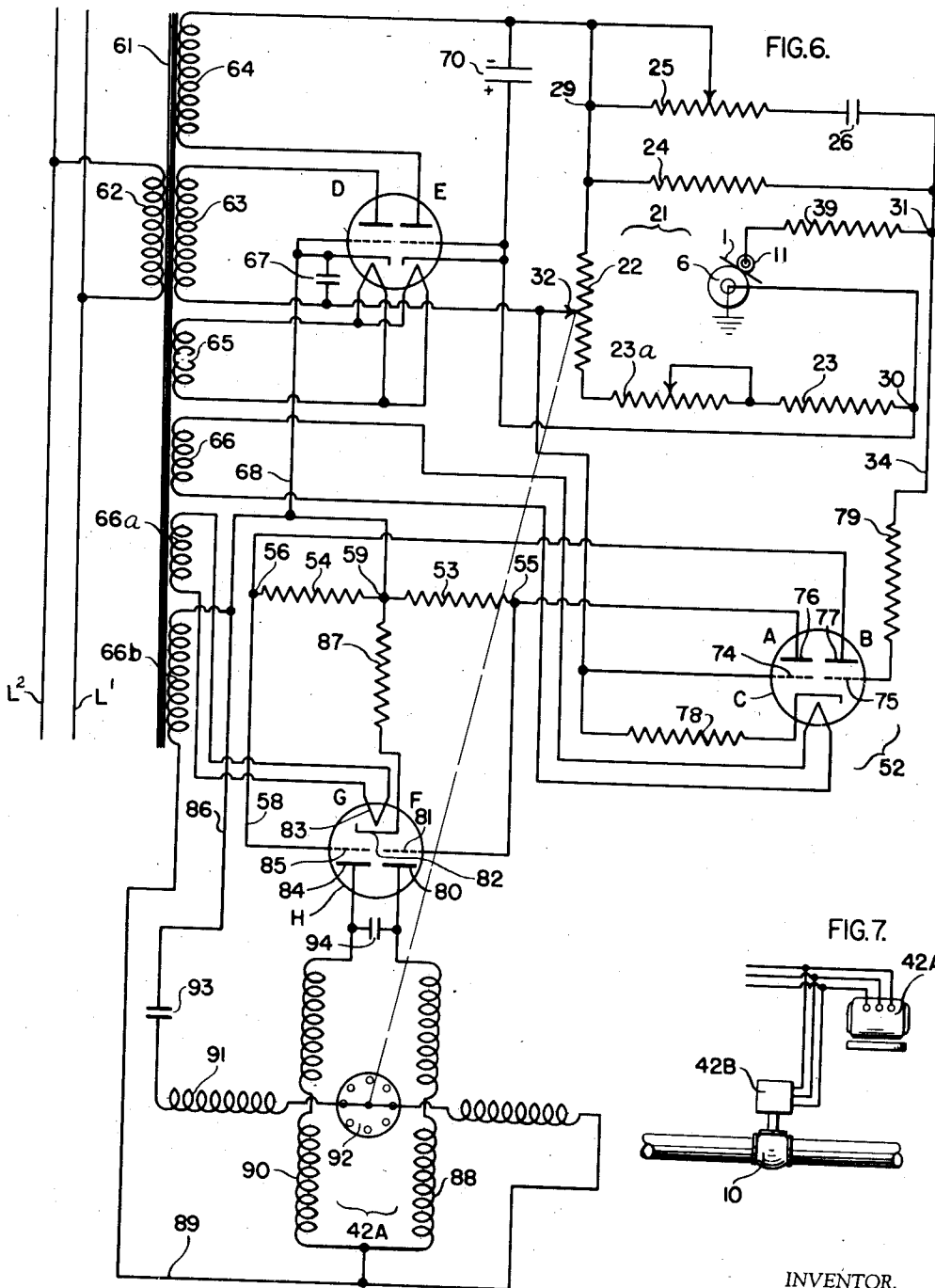
H. S. JONES

2,270,732

MEASURING AND CONTROL APPARATUS

Filed May 22, 1940

2 Sheets-Sheet 2



INVENTOR.

HARRY S. JONES

BY *E. B. Hangerberg*
ATTORNEY

UNITED STATES PATENT OFFICE

2,270,732

MEASURING AND CONTROL APPARATUS

Harry S. Jones, Philadelphia, Pa., assignor to The Brown Instrument Company, Philadelphia, Pa., a corporation of Pennsylvania

Application May 22, 1940, Serial No. 336,520

29 Claims. (Cl. 175-183)

The present invention relates to improvements in instruments for making electrical measurements and particularly to a method of and apparatus for rendering such instruments extremely stable in operation.

A general object of the invention is to provide an effective method of and apparatus for regulating a measurable condition such as mechanical, electrical, physical, etc., in such a manner as to prevent hunting.

A special object of the invention is to provide an improved method of and apparatus for measuring the moisture content of solid bodies such as textile, paper, and other sheets or webs, and the invention comprises features especially devised and adapted for use in measuring the moisture content of a moving web of material by measuring the electrical conductivity of the web.

For purposes of illustration, I have shown and hereinafter described in detail, the use of various forms of embodiment of the present invention in measuring the moisture content of a traveling web of warp yarn at the end of a sizing operation to which the yarn is subjected preparatory to its use in a weaving loom. It has been found necessary in the manufacture of woven fabrics by high speed weaving methods to condition the yarn so as to increase the strength thereof, or to increase its resistance to the friction or chafing to which it is subjected in the weaving operation, and such conditioning is commonly effected by subjecting the yarn to a sizing or so-called "slashing" treatment.

That treatment consists in the application to the yarn of a solution composed of suitable ingredients forming a protective coating on the yarn and its fibrous constituents and softening the threads to make them sufficiently pliable to bend about the filling threads in the woven goods. In the slashing operation it has been found that the best results are obtained when the sizing is applied to the warp after the latter has been wound on a warp beam, and while it is being unwound from the warp beam and wound up on a loom beam, as the final step in the preparation of the warp for insertion in the loom. In so slashing or sizing warp yarn it is desirable that the sized warp yarn, when wound on the loom beam should be at a suitably low temperature, and should have a moisture content, within a small range of variation, and much less than the moisture content of the yarn as it passes away from the sizing bath. To reduce the moisture content of the yarn as it passes away from the sizing bath, the yarn is moved

over steam heated drying drums or rolls, and is then cooled by passing it over a cooling roll.

The proper operation of the slashing machine is greatly facilitated by an accurate measurement of the moisture content in the web as it passes from the slasher proper to the loom beam on which it is wound, not only because the moisture content must be closely controlled, but also because in the operation of a properly designed slasher the maintenance of a suitable moisture content insures against risk of overheating the drying rolls and resultant burning or injuring of the warp yarn. That the range of variation in the moisture content of the warp should be narrow is practically essential, because a certain small moisture content in the yarn is desirable to permit evaporative cooling of the yarn and resultant dissipation of heat in the weaving operation, while a moisture content, but little greater than that required for the desired evaporative cooling action may result in the mildewing or discoloration of the fabric produced, and is otherwise objectionable in the weaving operation.

Heretofore various devices have been proposed for measuring the moisture content of webs and other substances in terms of electrical conductivity, one such form being disclosed in a co-pending application Serial No. 134,092 filed March 31, 1937, by Walter P. Wills for Measuring and control apparatus and now issued into Patent No. 2,215,805. The prior art devices, however, have been subject to instability of operation under conditions of rapid condition fluctuations because of their inability to distinguish between average and instantaneous changes in moisture content of the web under measurement, without requiring adjustments of the measuring instruments which render them sluggish in operation. For many purposes the important measurements of the moisture content of a web, are not measurements of the moisture contents of small individual portions of the web, but are measurements of the average web moisture content from which the trend of change in the average moisture content of the web may be determined. On the other hand such average measurement should preferably not be made with the sacrifice of sensitivity.

Accordingly, a further specific object of the invention is to provide an improved method of and apparatus for determining the trend of change in the average moisture content of a moving web of material.

A still further specific object of the invention is to provide improved apparatus for determining

the trend of changes in the average moisture content of a moving web of material in which an extremely sensitive measuring instrument may be employed.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages and specific objects attained with its use, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described a preferred embodiment of the invention.

Of the drawings:

Fig. 1 is a diagrammatic representation of a warp sizing or "slasher" machine, and means associated therewith in accordance with the present invention for measuring the moisture content of the yarn after it has passed over the drying and cooling rolls of the slasher;

Fig. 2 is a schematic diagram illustrating a motor control circuit for automatically varying the supply of steam to the slasher drying drums to thereby vary their web drying action;

Fig. 3 is a schematic representation of one form of electrical measuring circuit adapted to be used in the Fig. 1 arrangement and embodying the invention;

Figs. 4-6 illustrate modifications of the Fig. 3 arrangement; and

Fig. 7 illustrates a modification of the control circuit of Fig. 2.

In Fig. 1 I have illustrated the use of my invention in measuring the electrical conductivity of a web of sized warp yarn as it leaves a sizing machine or "slasher" of conventional type. In the slasher shown in Fig. 1, the warp 1 is unwound from a warp beam 2 and is passed from the latter through a sizing bath in a sizing pan 3 over so-called squeeze rolls 4 to drying drums 5 whence the yarn passes over guide rolls 6 and a cooling drum 7 back of the final guide roll 6 onto a loom beam 8. The drying rolls 5 are heated by steam supplied through a pipe 9 at a rate regulated by a control valve 10 the adjustment of which is effected automatically by means to be described in accordance with the moisture content of the warp yarn. The moisture content of the warp yarn as it passes from the slasher proper to the warp beam 8 is measured by measuring the electrical conductivity of the warp yarn as it passes over the final guide roll 6 of the slasher.

To measure the electrical conductivity of the warp passing over the final guide roll 6, I employ an electrode or contact in the form of a conducting roll 11 which is held in contact with the warp passing between it and the final guide roll 6 by a suitable bias force, due, as shown, partly to gravity and partly to spring action. The guide roll 6 is connected to ground in ordinary practice, as a result of the grounding of the slasher frame in which the guide roll is journaled. The roll 11 is connected by a conductor 12 to a measuring circuit device 13 having a ground connection at 14 and means for amplifying variations in the current which flows through and varies with the conductivity of the warp passing between the roll 11 and adjacent roll 6. The current amplified by the device 13 is measured by an electrical measuring instrument 15 which may be of any suitable type, and as shown is a "Brown potentiometer" control instrument of commercial type, one form of which

is disclosed in the Harrison Patent 1,946,280 issued February 6, 1934. When the instrument 15 is a control instrument it may include provisions for automatically adjusting the operation of the slasher as required to maintain the moisture content of the warp in engagement with the contact roll 11 at an approximately constant predetermined value, or the measurements furnished by the instrument 15 may be utilized in the manual control of the slasher operation.

In controlling the operation of the slasher so as to maintain a constant moisture content in the warp being wound on the loom beam 8 the supply of steam to the drying rolls 5 may be kept constant and the speed of travel of the warp over the drying rolls varied as required or, as illustrated in Fig. 1, the speed of travel of the warp may be kept constant and the supply of steam to the drying rolls varied. I prefer to operate the slasher in accordance with the latter method inasmuch as greater insurance is then had that the amount of size taken up by each short longitudinal section of the warp will remain constant.

In Fig. 2 I have illustrated one form of means for controlling the adjustment of the steam valve 10 under control of the measuring circuit device 13 described in detail hereinafter and thereby in accordance with the moisture content of the warp. As illustrated, a reversible series type electrical motor 16 is provided for adjusting the valve 10, which motor is energized from electrical current supply conductors L¹ and L² and is selectively controlled for operation in one direction or the other by the closure of one or the other of two control switches 17 and 18 connected in circuit with a forward winding 19 and a reverse winding 20 of the motor, respectively.

In operation when the moisture content of the warp yarn engaging the contact roll 11 is greater than that desired, the switch 17 is closed and the motor 16 then operates in the direction to increase the supply of steam to the drying rolls 5 and thereby to increase the drying action of the rolls 5 on the warp yarn. Conversely, when the moisture content of the warp engaging the contact roller 11 is less than that desired, the switch 18 is closed and the motor 16 operates in the direction to decrease the supply of steam to the drying rolls 5 and thereby decrease the warp drying effect of the rolls 5.

The electrical measuring circuit included in the device 13 may take various forms, some of which are illustrated more or less diagrammatically in Figs. 3-6. The circuit arrangement shown in Fig. 3 comprises a balanced Wheatstone bridge 21, one arm of which includes the resistance of the web whose moisture content is being measured and the other arms of which include resistances 22, 23 and 24, the latter of which is shunted by a resistance 25 and a condenser 26 connected in series and the purpose of which is explained hereinafter.

A standardizing resistance 23a may desirably be provided in the bridge network arm including the resistance 23. Energizing current is supplied the bridge network 21 from a suitable source of direct current, for example, from a battery 27 having its terminals connected through an adjustable resistance 28 to the opposed bridge junctions 29 and 30. The opposed normally equipotential junctions comprising a fixed junction 31 and the point of engagement of a contact 32 with the resistance 22 are connected by conductors 34 and 35 to the terminals

of a galvanometer 33 having a resistance 36 connected in shunt therewith. As shown the conductor 35 is connected to one end of resistance 36 and the conductor 34, in which a resistance 37 is inserted, is connected to a contact 38 which contact may be manually adjusted along resistance 36 for varying the sensitivity of the galvanometer. A resistance 39 is connected in the bridge arm including the web under measurement and is desirably provided to permit the measurement of lower values of web-resistance and to protect the galvanometer 33 from damage in the event of the contact roll 11 being connected directly to ground. The standardizing resistance 23a referred to above is provided to calibrate the instrument so that, when the resistance between the contact roll 11 and the roll 6 is zero, the bridge network 21 will be balanced with the contact 32 in its lowest position as seen in Fig. 3.

In operation with the normal balanced condition of the Wheatstone bridge circuit 21, the bridge junctions 31 and 32 will be at the same potential and the pointer 40 of the galvanometer 33 will then be in its neutral or zero position. On a decrease in the moisture content of the warp in contact with the roller 11 the increase in value of the warp resistance results in an increased potential drop in the bridge arm including the warp resistance and thus produces an unbalanced voltage in the bridge network to render the junction 32 positive with respect to the junction 31 and thereby to produce deflection of the galvanometer pointer 40 in a corresponding direction. Conversely, an increase in the moisture content of the warp in contact with the roll 11 and the resultant reduction in the value of the warp resistance increases the potential of the junction 31 with respect to the junction 32 to cause a deflection of the galvanometer pointer 40 in the opposite direction.

The pointer 40 of the galvanometer will deflect in one direction or in the opposite direction from its neutral position as the potential of the bridge junction 31 rises above or falls below the potential of the junction 32 and the deflective position of the pointer 40 might be relied upon to furnish an indication of the magnitude of the moisture content of the warp, or extent of its departure from a predetermined value thereof, if the circuit included no rebalancing provisions, such predetermined value being determined by the existing adjustment of resistor 23a. A more accurate measure of the moisture content variation is furnished in the circuit shown in Fig. 3 by the position of the movable contact 32 when the latter is adjusted as required to rebalance the bridge following any change in the warp moisture content and value of the warp resistance.

When the bridge network 21 is unbalanced as a result of a decrease in the moisture content of the warp and consequent increase in the warp resistance making the potential of the junction 31 lower than that of the junction 32, the bridge may be rebalanced by adjusting the contact 32 in an upward direction as seen in Fig. 3. Conversely, when the bridge is unbalanced as a result of an increase in the warp moisture content and resultant reduction in the value of the warp resistance making the potential of the bridge junction 31 higher than that of the junction 32, the bridge may be rebalanced by a suitable adjustment of the contact 32 in a downward direction.

Preferably the contact 32 is automatically ad-

justed as required to rebalance the bridge. In obtaining this end, the galvanometer 33 is adapted on deflection of its pointer 40 in one direction or the other from its normal neutral, or zero position, to energize a reversible electrical motor 41 for operation in one direction or in the opposite direction. As diagrammatically shown, the motor 41 comprises a rotatable armature 42 and separate forward and reverse windings 43 and 44 respectively, each connected at one end through the armature 42 to an electrical current supply conductor L¹. The cooperating supply conductor L² is connected to the galvanometer pointer 40 which engages the second end of and thereby energizes one or the other of the windings 43 and 44 on the deflection of the pointer in one direction or the other from its neutral, or zero position. The armature 42 drives a threaded shaft 45 through suitable gearing not shown, which shaft carries a nut 46 which is adjusted longitudinally of the shaft when the latter is rotated. The nut 46 carries the contact 32. On the assumption that a decrease in the warp moisture content results in a counter-clockwise deflection of the pointer 40 bringing the latter into engagement with a terminal of winding 43, the motor 41 then operates in the direction to adjust the contact 32 in an upward direction. Conversely, on an increase in the warp moisture content and the clockwise deflection of the pointer 40 from its neutral position into engagement with a terminal of winding 44, the motor is then set into rotation in the direction to rebalance the bridge by adjusting the contact 32 in a downward direction.

As will be apparent the motor 41 may be suitably connected to control switches 17 and 18 which may be identical to the correspondingly identified parts of Fig. 2 and made to operate one or the other of the control switches into closed position while simultaneously effecting balancing adjustments of the contact 32 along the resistance 22 to thereby effect variations in the supply of steam to the drying rolls 5 and hence to effect variations in the web drying effect of the rolls. In Fig. 3 the control switches 17 and 18 have been shown as mounted on a circular disc 47 which is connected through suitable gearing to the shaft of motor 41. The control switches are so mounted that as the motor causes balancing adjustments of the contact 32 in one direction or the other from a predetermined position along the resistance 22 corresponding to the desired moisture content value, one or the other of the control switches will be actuated into its closed position and a corresponding adjustment of the web drying effect of the rolls will be effected to restore the moisture content to said value. Disc 47 may be adjusted relative to armature 42 in any suitable manner to determine the desired control value.

For example, when the warp moisture content becomes greater than is desirable, the motor 41 will be energized for rotation in the proper direction to effect a downward balancing adjustment of the contact 32 as seen in Fig. 3 and to simultaneously cause rotation of the disc 47 in a clockwise direction for actuating the switch 17 into closed position. The control switches 17 and 18 of Fig. 3 may be connected to motor 16 and the electrical current supply conductors L¹ and L² so that closure of one or the other results in energization of the motor 16 in the direction to effect the desired change in the web drying effect. Closure of switch 17 will then cause an

increase in the supply of steam to the drying rolls 5, resulting in a decrease in moisture content of the warp. Conversely, closure of the switch 18 will cause a decrease in the supply of steam to the drying rolls and thereby result in a higher value of moisture content in the warp.

In lieu of the relay mechanism including the galvanometer controlled reversible motor 41 shown in Fig. 3 other forms of galvanometer controlled relay mechanisms may be employed to automatically adjust the contact 32. Thus, for example, when the potentiometer 15 is of the "Brown potentiometer" type, comprising a mechanical relay mechanism, including as its actuating element a constantly rotating shaft which intermittently rebalances a potentiometer circuit in response to deflection of the instrument galvanometer associated with that circuit, the instrument can be used without change other than in its circuit connections to effect the slide wire resistance adjustment purposes effected in Fig. 3 by the use of the galvanometer controlled motor 41.

In order to permit the use of an extremely sensitive galvanometer 33 and at the same time render the network insensitive to instantaneous changes in moisture content of the warp, for example, changes due to varying moisture contents of small individual portions of the warp, means have been provided in the form of the resistance 25 and condenser 26 shunted across the bridge arm including the resistance 24 in the arrangement of Fig. 3. With the moisture content of the warp at a given value the condenser 26 will be charged to a corresponding extent and, due to the action of resistance 25 which permits only slow leakage of the charge therefrom, or slow charging thereof, tends to maintain that charge. Thus, if instantaneous variations in the warp resistance occur, a corresponding bridge unbalance effect will not occur due to the action of resistance 25 and condenser 26, and the galvanometer 33, although extremely sensitive, will not respond to such changes. If the change in warp resistance persists, however, the condenser 26 will charge or discharge accordingly as the warp resistance increases or decreases, and thereby permit an unbalancing action of the bridge network to which the galvanometer 33 responds substantially instantaneously. The extent to which the condenser 26 delays the response of the system to changes in warp moisture content may be varied by adjustment of the value of resistance 25, which, as shown, is adjustable.

It is noted that subsequent adjustment of the contact 32 relatively to the resistance 22 produced as a result of deflection of the galvanometer pointer 40 is effective immediately to rebalance the bridge network and is not subject to the delayed action introduced by the resistance 25 and condenser 26. Thus, in effect, means have been provided for rendering the system insensitive to instantaneous changes in the warp moisture content without sacrificing any sensitivity of the galvanometer 33. This feature is to be especially noted because one drawback of prior art attempts to solve this problem has been the sacrifice of galvanometer sensitivity.

The embodiment of the invention disclosed in Fig. 4 is similar to that just described except that an alternative arrangement has been shown for averaging the instantaneous changes in the warp moisture content. Also there is disclosed

in this embodiment the use of copper oxide rectifying means 48 in obtaining a source of direct current for the Wheatstone bridge network from the commercial alternating current supply conductors L¹ and L² instead of from a battery 27 as disclosed in Fig. 3. It will be understood, however, that a battery 27 may be employed in the arrangement of Fig. 4, if desired and also that the rectifying means of Fig. 4 may be employed in the arrangement of Fig. 3.

As illustrated in Fig. 4, the resistance of warp 1 and resistance 39 comprise one arm of a Wheatstone bridge network 21a, which bridge network may be exactly like the bridge network 21 of Fig. 3 except that in lieu of the connection of resistance 25 and condenser 26 in series and shunting resistance 24 of the latter arrangement, a resistance 25a is connected in series with the resistance 24, and a condenser 26a is connected in shunt to the resistance 25a. The output terminals of the copper oxide rectifier 48 are connected to the energizing junctions 29 and 30 of the bridge network 21a and the input terminals of said rectifier are connected to the terminals of the secondary winding 49 of a transformer 50 having a line voltage primary winding 51 connected to the alternating current supply conductors L¹ and L². No rebalancing means have been shown in Fig. 4 but it will be understood that a rebalancing action of the bridge network 21a may be effected in precisely the same manner in which the bridge network 21 of Fig. 3 is rebalanced.

The resistance 25a and condenser 26a in this arrangement operate as do the resistance 25 and condenser 26 of Fig. 3, to prevent the bridge network 21a from being unbalanced in response to instantaneous changes in warp resistance and permit the use of an extremely sensitive galvanometer 33 and also instantaneous rebalancing of the bridge network by adjustment of contact 32 along resistance 22.

In Fig. 5 I have illustrated, more or less diagrammatically a further modification of the measuring circuit arrangement of Fig. 3 in which any unbalance of the Wheatstone bridge network 21 is not measured directly by a galvanometer 33, but in which such unbalance is amplified by a suitable amplifier 52 to be described and the amplified quantity is applied to the terminals of said galvanometer thereby obtaining greater accuracy and sensitivity of measurement.

As illustrated, the amplifier 52 comprises a balanced Wheatstone bridge two adjacent arms of which include balanced triode elements A and B respectively, of the hot cathode type and preferably contained in a single envelope C. The other two bridge arms include resistances 53 and 54 respectively, in series with the elements A and B and of equal value. The opposed normally equipotential junctions 55 and 56 of the amplifier bridge are connected by conductors 57 and 58 to the terminals of a galvanometer 33 which galvanometer may be identical to the correspondingly identified part of the Fig. 3 arrangement and has a shunt resistance 36 and a series resistance 37 associated therewith as in the latter arrangement. The other two opposed junctions 59 and 60 of the amplifier bridge are connected to a suitable source of direct current, which, in this arrangement, comprises a power transformer 61 having a line voltage primary winding 62 connected between the supply conductors L¹ and L², and two high voltage secondary windings 63 and 64. One terminal of

the secondary winding 63 is connected to the anode of an indirectly heated type half wave rectifier valve D and the other terminal is connected through a filtering condenser 67 to the cathode of said valve. The terminal of condenser 67 which is connected to the cathode of valve D is positive with respect to its other terminal and is connected by a conductor 68 to the amplifier bridge terminal 59. The negative terminal of condenser 67 is connected by a conductor 69 to the amplifier bridge terminal 60.

Energizing current is supplied the filament of valve D from the transformer secondary winding 65 which winding also supplies energizing current to the heating filament of a half wave rectifier valve E which also is of the indirectly heated type. Valve E supplies direct current to the bridge network 21 and, as illustrated, has its anode connected to one terminal of the transformer secondary winding 64 the other terminal of which is connected through a filtering condenser 70 to the cathode of said valve. The positive terminal of condenser 70 is connected by a conductor 71 to the junction 30 of the bridge network 21 and the negative terminal thereof is connected to the junction 29 of said bridge.

As illustrated, the triodes A and B have a common cathode 72 which is heated by a filament 73 energized from the transformer secondary winding 66 and also include respective control electrodes 74 and 75 and respective anodes 76 and 77. The anodes 76 and 77 are connected to the junctions 55 and 56, respectively, and through the resistances 53 and 54 to the positive terminal of condenser 67 and the cathode 72 is connected through a biasing resistance 78 and conductors 35 and 69 to the negative terminal of the condenser 67. The control electrode 74 is connected by the conductor 35 to the junction 60, which junction is connected to the movable contact 32 in engagement with the resistance 22, and the control electrode 75 is connected to the junction 31 of bridge 21 by the conductor 34 in which a resistance 79 is inserted. In operation a biasing voltage is produced across the resistance 78 in the cathode circuit which renders the potential of the control electrode 74 negative with respect to the potential of the cathode 72.

As previously indicated the triodes A and B should be balanced, or matched, so that they have similar characteristics and to this end they are both preferably contained in the same envelope C since the desired identity in characteristics of the triodes is more certainly insured by enclosing them in the same tube than if enclosed in separate tubes.

In operation with the normal balanced condition of the amplifier bridge circuit shown in Fig. 5 the potentials of the control electrodes 74 and 75 are similarly negative relative to the cathode 72 whereby the triodes A and B are equally conductive and the current flows through the bridge arm resistances 53 and 54 are equal and the bridge junction points 55 and 56 are therefore at the same potential and the pointer 40 of the galvanometer 33 will then be in its neutral or zero position. On a decrease in the moisture content of the warp in contact with the roller 11, the increase in the value of the warp resistance results in an increased potential drop in the bridge arm including the warp resistance and thus produces an unbalanced voltage in the bridge circuit 21 to decrease the potential of the junction 31 with respect to the junction 32 and thereby to increase the extent to which the potential

of the control electrode 75 is negative relative to the cathode 72. This action operates to diminish the conductivity of the triode B and makes the potential of the bridge junction 56 higher, or more positive, than the potential of the junction 55. Conversely, an increase in the moisture content of the warp in contact with the roll 11 and resultant reduction in the value of warp resistance increases the potential of the bridge junction 31 with respect to the junction 32 resulting in an increase in the conductivity of triode B and thereby in a decrease in potential of the junction 56 relative to the junction 55.

In this arrangement, as in the previous arrangements described, on variation in the value of warp moisture content the bridge network 21 may be rebalanced by adjustment of contact 32 relative to resistance 22. The contact 32 may be automatically adjusted as required for bridge rebalancing purposes by a relay mechanism under control of the galvanometer pointer 40 and which may be of the character employed to adjust the contact 32 of Fig. 3.

As illustrated in Fig. 6, the general circuit provisions of Fig. 5 may be employed in a self balancing electrical system not including a galvanometer, but in which the rebalancing adjustments of contact 32 are effected by a motor 42A corresponding generally to the motor 42 of Fig. 3 but controlled directly from the amplifier 52 instead of through a galvanometer. The motor 42A is connected in the output circuits of a pair of balanced triode elements F and G which are preferably contained in a single envelope H and is selectively energized for rotation in one direction or the other accordingly as the conductivity of one triode F or G is rendered different from the other in response to unbalance of bridge 21.

The output circuits of the triodes A and B of the amplifier 52 which is responsive to unbalance of bridge 21, are coupled by the resistances 53 and 54 to the input circuits of the triodes F and G. The triodes F and G are illustrated as of the hot cathode type and as shown triode F includes an anode 80, a control grid 81, a cathode 82 and a heater filament 83. The triode G includes the cathode 82 and heater filament 83, which elements are common to both triodes F and G, and also includes an anode 84 and a control grid 85. The heater filament 83 is connected to a secondary winding 66a provided on the transformer 61 and receives energizing current therefrom. Anode voltage is supplied the triodes F and G from a secondary winding 66b, provided on the transformer 61, through a circuit which may be traced from the upper terminal of secondary winding 66b to a conductor 86, a cathode biasing resistance 87, the cathode 82, to a parallel network including in one branch the anode to cathode resistance of triode F, a winding 88 of motor 42A, and a conductor 89 to the lower terminal of transformer secondary winding 66b. The other branch of the parallel network referred to includes the anode to cathode resistance of triode G and a winding 90 of motor 42A to the conductor 89 and the lower terminal of transformer secondary winding 66b.

As illustrated, the motor 42A is of the induction variety and includes three windings, namely, the windings 88 and 90 and a winding 91, and a squirrel cage rotor 92 with which two pairs of oppositely disposed field poles (not shown) are associated. Winding 91 is wound on one pair of said field poles and windings 88 and 90 are wound on the other pair of poles, one half of

winding 88 being wound on a portion of one of the field poles which is adjacent the rotor 92, and the other half being wound on portion of the other pole remote from said rotor. Similarly, one half of winding 90 is wound on a portion of the last mentioned pole adjacent the rotor 92, and the other half of winding 90 is wound on a portion of the first mentioned pole remote from said rotor.

As illustrated, winding 91 is connected to the transformer secondary winding 66b through a suitable condenser 93 so that the current which flows through this winding will lead the voltage supplied by the winding 66b by approximately 90°. Winding 88 is energized by the current flow conducted by the triode F and the third winding 90 is energized by the current flow conducted by the triode G. A condenser 94 of suitable value is connected between the anodes 80 and 84 of the triodes F and G. Windings 88 and 90 are so wound on motor 42A with respect to the manner in which winding 91 is wound thereon that when they are equally energized rotor 92 will not be actuated for rotation in either direction but will remain stationary. When one winding 88 or 90 is energized to a greater extent than the other, however, the rotor 92 will be actuated for rotation in a corresponding direction. That is to say, when the anode to cathode resistance of triode F is approximately equal to anode to cathode resistance of the triode G, the torque developed by winding 88 for producing rotation of the rotor will be equal and opposite to the torque developed by the winding 90 and accordingly the rotor will remain stationary. When the anode to cathode resistance of one valve G or F is decreased or increased with respect to the other, however, the torque developed by winding 90 with respect to that developed by winding 88 will be increased and decreased, respectively, and the rotor 92 will be actuated for rotation in a corresponding direction.

By virtue of the connection of the output circuits of triodes A and B to the input circuits of triodes F and G, the anode to cathode resistance of each of the latter triodes is controlled in accordance with the conductivity of the triodes A and B. The relative conductivities of the triodes A and B, as explained previously in connection with the arrangement in Fig. 5, are controlled by the bridge network 21 so that on unbalance of the latter in one direction, the triode B is rendered more conductive than the triode A while on unbalance of the bridge network in the opposite direction the conductivity of the triode B is decreased with respect to that of the triode A. When the conductivities of the triodes A and B are the same, the conductivities of the triodes F and G will be the same and consequently the motor 42A will not be actuated for rotation in either direction and will remain stationary. When the bridge network 21 is unbalanced in one direction or the other, however, the conductivity of triode B will be correspondingly increased or decreased and accordingly the conductivity of the triode G will be decreased or increased with respect to the conductivity of triode F to produce rotation of the motor 42A in a corresponding direction.

Fig. 7 discloses an alternative control arrangement to that illustrated in Figs. 2 and 3. In Fig. 7, a reversible electrical motor 42B, which may be exactly like the motor 42A of Fig. 6, is shown

connected in parallel with motor 42A of Fig. 6 to directly operate the valve 10 of Fig. 1.

In the forms of Figs. 3, 4 and 5 and without the control provisions of Fig. 2, my present invention provides averaging means avoiding undesirable erratic measurements due to "hunting," while coupled with the control means of Figs. 2 or 7, "hunting" or oscillation of the control is minimized. The hunting elimination for the measurement purpose above is especially desirable in the form of Fig. 6 wherein the inertia of the rebalancing motor 42A would otherwise cause overtravel.

While in accordance with the provisions of the statutes I have illustrated and described preferred embodiments of the present invention, those skilled in the art will understand that changes may be made in the form of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims, and that some features of the present invention may sometimes be used with advantage, without a corresponding use of other features.

Having now described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. The method of measuring the value of a variable condition having the characteristic of normally fluctuating in magnitude about an average value at a rate more rapid than the period of response of a measuring instrument utilized in the measurement of the value of said condition comprising the steps of producing an effect in accordance with the average value of said condition during a predetermined time interval which time interval is of duration greater than the period of response of said measuring instrument, opposing said effect to a second effect, measuring the difference in magnitude between said first and second mentioned effects by means of said instrument, varying said second mentioned effect in accordance with the measurement of said instrument to reduce said difference substantially to zero, and measuring the magnitude of said second mentioned effect.

2. The method of measuring the moisture content of a moving web the moisture content of the successive portions of which normally fluctuate in magnitude about an average value at a rate more rapid than the period of response of a measuring instrument utilized in the measurement of the value of the moisture content of said web comprising the steps of measuring the electrical conductivity of successive portions of said web, producing an effect in accordance with the average value of the electrical conductivity of the successive portions of said web during a predetermined time interval which time interval is of duration greater than the period of response of said measuring instrument, opposing said effect to a second effect, measuring the difference in magnitude between said first and second mentioned effects by means of said instrument, varying said second mentioned effect in accordance with the measurement of said instrument to reduce said difference substantially to zero, and measuring the magnitude of said second mentioned effect.

3. Apparatus for measuring the magnitude of a variable condition comprising a self balancing system adapted to be unbalanced on deviation of said variable condition from a predetermined value, means to rebalance said system on unbalance thereof, means responsive to the state of

balance of said system to control said rebalancing means, and means included in said system to render said responsive means unresponsive to transitory changes in the magnitude of said variable condition without affecting the sensitivity of response of said responsive means to changes in the state of balance of said system.

4. Apparatus for measuring the magnitude of a variable condition comprising a self balancing system adapted to be unbalanced on deviation of said variable condition from a predetermined value, means to rebalance said system on unbalance thereof, means responsive to the state of balance of said system to control said rebalancing means, and means included in said system to render said responsive means unresponsive to transitory changes in the magnitude of said condition without affecting the operation of said rebalancing means in restoring the balance of said system on unbalance thereof.

5. Apparatus for measuring the magnitude of a variable condition comprising a self balancing system adapted to be unbalanced on deviation of said variable condition from a predetermined value, means to rebalance said system on unbalance thereof, means responsive to the state of balance of said system to control said rebalancing means, and means included in said system to render said responsive means unresponsive to transitory changes in the magnitude of said condition without introducing delay in the rebalancing effect of operation of said rebalancing means.

6. Apparatus for measuring the magnitude of a variable condition comprising a self balancing electrical network adapted to be unbalanced on deviation of said variable condition from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means, and means having a connection with said network to render said responsive means unresponsive to transitory changes in the magnitude of said condition without affecting the sensitivity of response of said responsive means to changes in the state of balance of said system.

7. Apparatus for measuring the magnitude of a variable condition comprising a self balancing electrical network adapted to be unbalanced on deviation of said variable condition from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means, and means connected to said network to render said responsive means unresponsive to transitory changes in the magnitude of said condition without affecting the operation of said rebalancing means in restoring the balance of said network on unbalance thereof.

8. Apparatus for measuring the magnitude of a variable condition comprising a self balancing electrical network adapted to be unbalanced on deviation of said variable condition from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means, and means connected to said network to render said responsive means unresponsive to transitory changes in the magnitude of said condition without introducing delay in the rebalancing effect of operation of said rebalancing means.

9. Apparatus for measuring the conductivity of a substance including an adjustable exhibiting device, a self balancing electrical network

adapted to be unbalanced only on sustained deviation of the conductivity of said substance from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means and to control the adjustment of said exhibiting device, and means included in said circuit to render said responsive means unresponsive to transitory changes in the conductivity of said substance without affecting the sensitivity of response of said responsive means to unbalance of said network.

10. Apparatus for measuring the conductivity of a substance including an adjustable exhibiting device, a self balancing electrical network adapted to be unbalanced only on sustained deviation of the conductivity of said substance from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means and to control the adjustment of said exhibiting device, and means included in said circuit to render said responsive means unresponsive to transitory changes in the conductivity of said substance without affecting operation of said rebalancing means in restoring the balance of said network on unbalance thereof.

11. Apparatus for measuring the conductivity of a substance including an adjustable exhibiting device, a self balancing electrical network adapted to be unbalanced only on sustained deviation of the conductivity of said substance from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means and to control the adjustment of said exhibiting device, and means included in said circuit to render said responsive means unresponsive to transitory changes in the conductivity of said substance without introducing delay in the rebalancing effect of operation of said rebalancing means.

12. Apparatus for measuring the magnitude of a variable condition comprising a self balancing electrical network adapted to be unbalanced on deviation of said variable condition from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means, and means connected to said network to render said responsive means unresponsive to transitory changes in the magnitude of said condition without affecting the sensitivity of response of said responsive means and without affecting the operation of said rebalancing means in restoring the balance of said network on unbalance thereof.

13. Apparatus for measuring the moisture content of a moving web including an adjustable exhibiting device, a normally balanced electrical network adapted to include the electrical resistance of successive portions of said web therein and adapted to be unbalanced on deviation in the average resistance of said web from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means and to control the adjustment of said exhibiting device, and means included in said network to render said responsive means unresponsive to substantial differences in the electrical resistance of adjacent portions of said web without affecting the sensitivity of response

of said responsive means to unbalance of said network.

14. Apparatus for measuring the moisture content of a moving web including an adjustable exhibiting device, a normally balanced electrical network adapted to include the electrical resistance of successive portions of said web therein and adapted to be unbalanced on deviation in the average resistance of said web from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means and to control the adjustment of said exhibiting device, and means included in said network to render said responsive means unresponsive to substantial differences in the electrical resistance of adjacent portions of said web without affecting the operation of said rebalancing means in restoring the balance of said network on unbalance thereof.

15. Apparatus for measuring the moisture content of a moving web including an adjustable exhibiting device, a normally balanced electrical network adapted to include the electrical resistance of successive portions of said web therein and adapted to be unbalanced on deviation in the average resistance of said web from a predetermined value, means to rebalance said network on unbalance thereof, means responsive to the state of balance of said network to control said rebalancing means and to control the adjustment of said exhibiting device, and means included in said network to render said responsive means unresponsive to substantial differences in the electrical resistance of adjacent portions of said web without affecting the sensitivity of response of said responsive means on unbalance of said network and without affecting the operation of said rebalancing means in restoring the balance of said network on unbalance thereof.

16. Apparatus for measuring the magnitude of a variable condition including an adjustable exhibiting device, a normally balanced system adapted to be unbalanced on deviation in the magnitude of said condition from a predetermined value, means responsive to the state of balance of said system to control the adjustment of said exhibiting device, and means included in said system to render said responsive means unresponsive to transitory changes in the magnitude of said condition without affecting the sensitivity of response of said responsive means to unbalance of said system.

17. Apparatus for measuring the moisture content of a moving web including an adjustable exhibiting device, a normally balanced electrical network adapted to include the electrical resistance of said web therein and adapted to be unbalanced on deviation in the average resistance of said web from a predetermined value, means responsive to the state of balance of said network to control the adjustment of said exhibiting device, and means included in said network to render said responsive means unresponsive to transitory changes in the electrical resistance of said moving web without affecting the sensitivity of response of said responsive means.

18. Self balancing apparatus including an electrical bridge network one arm of which includes a resistance the magnitude of which varies in accordance with the magnitude of a variable condition and the other arms of which include other resistances, one of said other resistances being adjustable to rebalance said bridge

network when the latter is unbalanced due to deviation in said variable resistance from a predetermined value, means responsive to unbalance of said bridge network for adjusting said adjustable resistance to rebalance said network, and means included in said bridge network to render said responsive means unresponsive to transitory changes in the value of said variable resistance without affecting the sensitivity of response of said rebalancing means to unbalance of said bridge network.

19. Self balancing apparatus including an electrical bridge network one arm of which includes a resistance the magnitude of which varies in accordance with the magnitude of a variable condition and the other arms of which include other resistances, one of said other resistances being adjustable to rebalance said bridge network when the latter is unbalanced due to deviation in said variable resistance from a predetermined value, means responsive to unbalance of said bridge network for adjusting said adjustable resistance to rebalance said network, and means included in said bridge network to render said responsive means unresponsive to transitory changes in the value of said variable resistance without introducing delay in the rebalancing effect of adjustment of said adjustable resistance.

20. Self balancing apparatus including an electrical bridge network one arm of which includes a resistance the magnitude of which varies in accordance with the magnitude of a variable condition and the other arms of which include other resistances, one of said other resistances being adjustable to rebalance said bridge network when the latter is unbalanced due to deviation in said variable resistance from a predetermined value, means responsive to unbalance of said bridge network for adjusting said adjustable resistance to rebalance said network, and means to stabilize the operation of said last mentioned means including capacitative means connected in said bridge network and adapted to render the latter unresponsive to transitory changes in the value of said variable resistance.

21. Self balancing apparatus including a normally balanced electrical network, a plurality of impedances included in said network one of which varies in magnitude in accordance with the variations in magnitude of a variable condition, another one of said impedances being adjustable to rebalance said network when the latter is unbalanced due to deviation in said variable impedance from a predetermined value, means responsive to unbalance of said network for adjusting said adjustable impedance, and means to stabilize the operation of said last mentioned means including capacitative means adapted to render said network unresponsive to transitory changes in the value of said variable impedance without affecting the sensitivity of response of said responsive means.

22. Apparatus for measuring the conductivity of a variable resistance including an exhibiting device, an electrical bridge network having a pair of balancing junctions and including said variable resistance in one arm thereof and adapted to be unbalanced on deviation in said variable resistance from a predetermined value, connections between said balancing junctions of said bridge network and said exhibiting device, and means included in another arm of said bridge network to render the latter insensitive to transi-

tory changes in the value of said variable resistance.

23. Apparatus for measuring the conductivity of a variable impedance including an electrical current responsive device, a Wheatstone bridge network including said variable impedance in one arm thereof and adapted to be unbalanced on deviation in said variable impedance from a predetermined value, connections between the balancing junctions of said bridge network and said current responsive device, and means included in another arm of said bridge network to render the latter insensitive to transitory changes in the value of said variable impedance.

24. Apparatus for measuring the conductivity of a variable resistance including electrical current energizing means, an electrical bridge network energized by said means and having said variable resistance included in one of its arms and other resistances in its remaining arms, one of said other resistances being adjustable to rebalance said bridge network when the latter is unbalanced due to deviation in said variable resistance from a predetermined value, means responsive to unbalance of said bridge network for adjusting said adjustable resistance, and means connected to another one of said other resistances adapted to render the said bridge network insensitive to transitory changes in the value of said variable resistance.

25. The combination of claim 24 wherein the said last mentioned means includes a condenser connected in shunt to at least a portion of said another one of said other resistances.

26. The combination of claim 24 wherein the said last mentioned means includes a condenser and a resistance in series connected in shunt to at least a portion of said another one of said other resistances.

27. The combination of claim 24 wherein the

said last mentioned means do not affect the operation of said bridge rebalancing means in restoring the bridge network balance on unbalance thereof.

28. Apparatus for measuring the conductivity of a variable impedance including an electrical current responsive device, a Wheatstone bridge network including said variable impedance in one arm thereof and adapted to be unbalanced on deviation in said variable impedance from a predetermined value, an electronic amplifier to amplify the unbalance of said bridge network and having an input circuit and an output circuit, connections between the balancing junctions of said bridge network and the input circuit of said amplifier, connections between the said current responsive device and the output circuit of said amplifier, and means included in another arm of said bridge network adapted to render the latter insensitive to transitory changes in the value of said variable impedance.

29. Apparatus for measuring the conductivity of a variable resistance including an electrical current responsive device, a Wheatstone bridge network including said variable resistance in one arm thereof and adapted to be unbalanced on deviation in said variable resistance from a predetermined value, an electronic amplifier to amplify the unbalance of said bridge network and having an input circuit and an output circuit, connections between the balancing junctions of said bridge network and the input circuit of said amplifier, connections between the said current responsive device and the output circuit of said amplifier, and a condenser included in another arm of said bridge network to render the latter unresponsive to transitory changes in the value of said variable resistance.

HARRY S. JONES.