

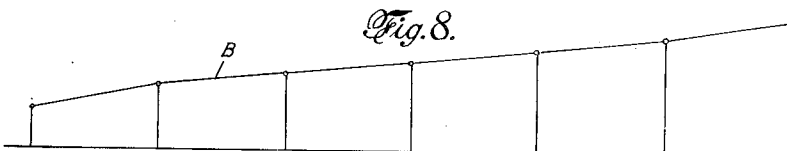
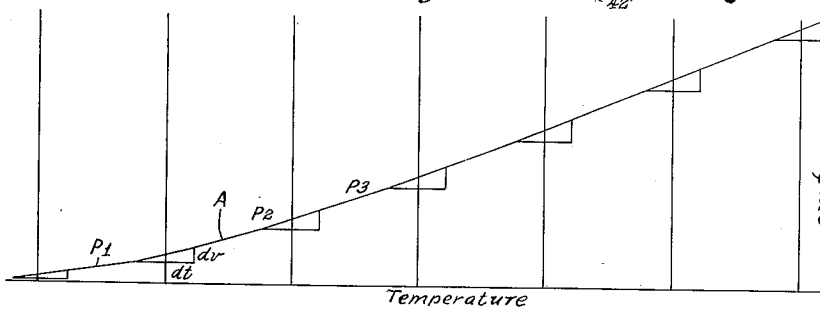
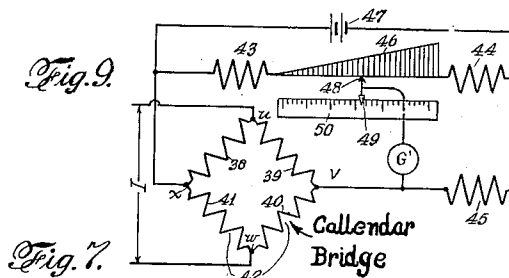
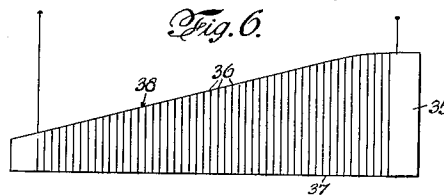
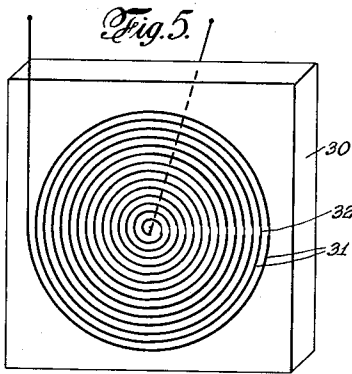
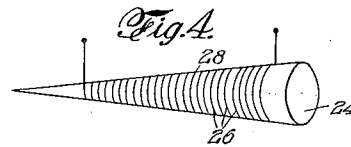
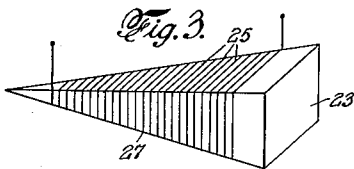
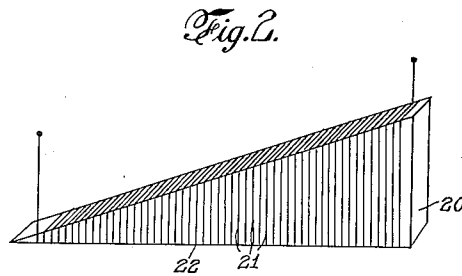
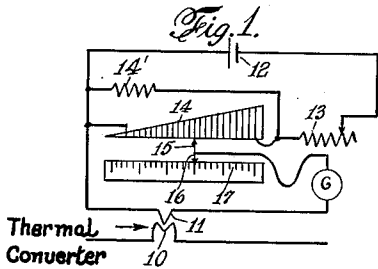
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P. A. BORDEN

2,114,330

COMPENSATED POTENTIAL DIVIDER FOR POTENTIOMETERS

Filed June 29, 1934



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COMPENSATED POTENTIAL DIVIDER FOR
POTENTIOMETERSPerry A. Borden, Waterbury, Conn., assignor to
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Application June 29, 1934, Serial No. 733,088

1 Claim. (Cl. 171—95)

The invention relates to electrical measuring and/or controlling apparatus of the potentiometer type, and more particularly to the construction of the slide-wire resistance element customarily utilized therein.

Ordinarily such resistance element comprises resistance wire wound uniformly upon a suitable form whereby its associated slider element, in contacting with successive sections of the winding, effects a uniform change in resistance value per increment of travel of the said slider element, care being exercised to secure absolute uniformity throughout the length of the wire. It has been proposed, as in U. S. Letters Patent #1,614,535, to reduce the potential drop per increment of slider travel by connecting a shunt resistance about a selected portion of the resistance element adapted normally to carry the total slide-wire current. By this expedient, an increased proportion of the total number of increments of movement of the slider element are required to compensate for variation in certain electrical conditions of the potentiometer circuits, as a result of the magnitude under measurement and/or control.

The present invention has for an object the provision of a slide-wire resistance element for use in a potentiometer to carry current uniformly throughout its length and whereby there may be afforded a non-uniform potential distribution along its length, as by introducing progressively and continuously varying values of resistance per increment of travel of the associated slider element over the engageable successive sections. The variation, for example, may be utilized to compensate for non-uniformity between the electromotive force measured by the potentiometer and a variable magnitude represented thereby, thus admitting of expressing, as scalar distances on a uniformly graduated scale, variable magnitudes having a non-linear characteristic.

Another object of the invention resides in the provision of an element of the aforesaid nature which may readily be designed to fit any predetermined law, whether empirical or expressed by a definite mathematical equation.

In carrying out the invention, the novel resistance element is formed by winding a resistance wire, of a uniform resistance characteristic throughout its length and adapted to carry uniformly the total slide-wire current, in such a manner that successive slider contacting sections thereof will afford non-uniform potential increments along the length of the winding, the resistance having progressively and continuously

varying values per increment of travel of the potentiometer slider element over the engageable successive sections of the slide-wire. This is conveniently effected by winding the wire over a form, preferably a flat element or card having one straight edge and the opposite edge of a contour following a curve representative of a mathematical function of a law or its first derivative, whereby compensation may be obtained for non-uniformity between the electromotive force measured by the potentiometer and a variable magnitude represented by such electromotive force.

Thus, in the provision of a smoothly tapered resistance element forming the slide-wire member of a measuring potentiometer, the variation in potential gradient due to a constant current flowing in the slide-wire is caused to have certain modifying effects upon the proportionality of the scale of the measuring instrument with which it is associated.

The nature of the invention, however, will best be understood when described in connection with the accompanying drawing, in which:

Fig. 1 is a diagrammatic view illustrating a simple potentiometer circuit and embodying the novel slide-wire element constituting the present invention.

Figs. 2 to 6, inclusive, illustrate various forms of the novel slide-wire resistance element.

Figs. 7 and 8 are diagrammatic views setting forth a graphical analysis of a method of computing the contour of a slide-wire card.

Fig. 9 is a diagrammatic view similar to Fig. 1, and illustrates the application of the invention to a Callendar bridge as one arm of a potentiometer network.

Referring to the drawing, more particularly Fig. 1, there is disclosed a potentiometer circuit, the term "potentiometer" being understood in the sense of an instrument for measuring an unknown potential difference by balancing it wholly or partially against a standard of electromotive force, or known potential difference obtained by passing a known current through a known resistance; and not in the sense in which it is sometimes used, as in radio and other controls, to designate merely rheostats having three terminals.

Thus, as indicated, the potentiometer shown is employed in the determination of the value of an electric current, through the use of a thermal converter. A resistance type heater is represented at 10, and may be operated with either direct or alternating current. Associated with the heater is a thermocouple 11 constituting with the resist-

ance 10 the thermal converter, for example, of the nature set forth in U. S. Letters Patent No. 1,765,563 to P. A. Borden et al., June 24, 1930, when applied to the measurement of electric
 5 current values. This couple applies its thermoelectromotive force to a potentiometer circuit in which is included a battery 12, a ballast and regulating rheostat 13 together with a uniformly tapered slide-wire resistance element or potential
 10 divider 14 constituting the novel feature of the present invention, and a galvanometer G connected thereto and to the thermocouple 11. A sliding contact or slider 15 is adapted to engage with successive exposed sections of the slide-wire
 15 and also to cooperate through a pointer or index 16 with a uniformly divided scale 17.

Assuming that the thermoelectromotive force is directly proportional to the temperature of the couple, it follows from well-known electrical principles that the voltage measured will vary as the
 20 square of the current in heater 10. Also, in accordance with the novel construction of the slide-wire element, as hereinafter set forth, the voltage across the portion of the slide-wire 14 between its
 25 left-hand end and the slider 15 may be caused to vary as the square of the distance of the said slider from that end. Hence, since by the basic principles of the potentiometer the two voltages
 30 are to be balanced, it follows that the deflection of the slider along the scale 17 is directly proportional to the measured current and the said scale may be made inherently uniform.

In order to have the potential gradient other than uniform, it becomes necessary that the
 35 cross-section, specific resistance or uniformity of winding of the wire be varied, or that the perimeter of the winding mandrel, as related to its length, follows a law governed by the law of desired change of potential gradient. For technical
 40 reasons, the systematic variation of any one of the first three variables aforesaid is manifestly more difficult than the design of a card or form as a mandrel having its perimeter varied in accordance with a predetermined law.

45 In the use of a wire having a uniform resistance characteristic throughout its length, the total resistance of the wire varies, of course, in direct proportion to such length; and if a wire of this nature be closely wound in a single layer on a
 50 mandrel, form, or card, its total length will be approximately proportional to the area of surface covered by the winding.

Also, if the number of turns in a given length of winding be sufficiently great, the length of
 55 wire, hence the resistance, and hence the voltage, between any two points, with a given constant current flow may be considered as being directly proportional to the area of the card or form, measured between the points under consideration.
 60 Thus, in the non-uniformly wound structures indicated in Figs. 2 to 5 inclusive, the voltage drop will be proportional to the area of wire-covered surface included between the points of reference, so that voltages measured between points on the
 65 forms of varying contour will vary as the square of the linear distance between these points, plus a constant quantity.

These structures may be of various shapes, for example, as indicated in Fig. 2 a wedge 20 has
 70 wound thereover an insulated wire 21 located uniformly thereon and having the insulation stripped over the portion 22 covering the straight edge or side of said wedge so as to leave a bare surface adapted to be engaged by a sliding contact, as the contact 15. Or, as indicated in Fig.

3, a pyramidal form 23 and in Fig. 4 a conical form 24 may be utilized and have respective windings 25 and 26 provided thereover with engaging surface portions 27 and 28 respectively for a corresponding slider (not shown).

The support may also partake of the nature of a flattened-out cone to afford a "pancake" coil or plaque, Fig. 5, in which the form is shown as a rectangular plate 30 with the resistance wire 31 set therein and extending in spiral form from the
 10 center of the plate. The wire is bared radially as at 32, and its total resistance will vary then as the square of the distance from the center.

Since for mechanical reasons resistance units having three-dimensional variations, such as the
 15 elements set forth in Figs. 2 to 4 inclusive, are likely to prove objectionable because of bulk, it is preferred to provide a support of substantially two dimensions or in the nature of a card. Thus, a card 35, Fig. 6, of uniform and substantially
 20 negligible thickness is wound with the wire 36, the winding being over its straight edge 37 and over the opposite edge 38 of a contour conforming to the desired voltage gradient, the area of the wound portion of the card, hence its resistance
 25 and the potential gradient, being then governed by the form of the contour. Therefore, by properly shaping such contour of the non-parallel side, the proportionality of the fall of potential along its length may be caused to follow any
 30 desired law.

Furthermore, from a mathematical analysis, it appears that the area of the wound portion of the card is representative of the integral of the law
 35 followed by the curve of the contour between chosen limits, or, in other words, that if the law followed by the variation of the measured quantity as related to the electromotive force be known in mathematical terms, the measurement by a
 40 potentiometric method may be reduced to a uniform scale by making the contour of the card to a curve representing the first derivative of this law.

An application of the principle lies in chemical or other technical measurements, wherein the
 45 measured electromotive force varies in relation to the quantity which it represents, by a logarithmic or exponential law (for instance in acidity measurement). Here the contour of the card is shaped in accordance with the first derivative of the
 50 law governing the relationship, and a uniformly divided scale is obtained.

Also, the thickness of the card does not introduce any deviation from the fundamental law of design, for the resistance of the transverse
 55 portion of the conductor is uniformly distributed throughout the length of the card, and it is therefore equivalent to a proportional increase of the non-variable portion of the card width, and thus equivalent to a modification in the value
 60 of a fixed shunt across the terminals of the card.

Moreover, since the potential of the sliding contact associated with a slide-wire resistance element depends solely upon its position along the
 65 said slide-wire element, and the law governing its variation does not change so long as the voltage across the total slide-wire element remains constant, it follows that the fundamental law of the system is in nowise disturbed by the presence of a shunt across the slide-wire, as in including
 70 the resistance 14' with the resistance 14, Fig. 1. By changing the value of this shunt 14', the range of the scale 17 may be varied at will without affecting the characteristic law of proportionality of the scale.

A further application of the principle of non-uniform variation lies in pyrometry, where, in the use of couples made of special alloys developed for high values of thermoelectromotive force, it is not unusual that the voltage change per degree temperature change varies from point to point throughout the range, according to a more or less irregular law, difficult of representation in any simple mathematical expression. In such cases compensation may be obtained without resort to higher mathematics by selecting a few points on the characteristic curve of the couple, and basing the ordinates of the contour of the card upon the slope of the curve at these points.

Following is a typical computation of a card contour for a thermocouple potentiometer in which it is required that the scale be uniform throughout the range: Referring to Figs. 7 and 8, the temperature/electromotive force curve of the couple is plotted as at A, Fig. 7, the length of the base of the curve being preferably chosen as equal to that of the scale of the instrument with which the thermocouple is to be associated. The said curve A is then subdivided into a number of equal portions as at p_1, p_2, p_3 , etc., and the increments

$$\frac{dv}{dt}$$

corresponding to each portion determined. These increments, to an enlarged scale, if necessary, are then plotted as the curve B, Fig. 8, having the same abscissae as the curve A. For example, the card shown in Fig. 6 may be constructed in this manner.

The contour of a card as determined by the method hereinbefore outlined, may be directly transferred to a sheet of suitable material for forming the card 35, Fig. 6, or it may be made the basis of a template or mold, which may be used in making a relatively large number of cards at one time. The said card being constructed of suitable sheet insulating material is then wound uniformly with the single layer 36 of insulated resistance wire of the proper characteristics, after which the insulation is stripped at 37 from the straight edge of the card, leaving a bare surface adapted to be engaged by a sliding contact element.

In Fig. 9 is shown a further application of the invention to the measurement of electric current by means of a circuit known as a "Callendar bridge", forming one arm of a potentiometer network. Four resistance arms 38, 39, 40, and 41, formed of material having a definite temperature coefficient of electrical resistivity, are mechanically associated so that there can be no material temperature difference among them, and connected in a closed loop 42 at points u, v, w , and x , and permanently adjusted to constitute a balanced bridge circuit, so that an electromotive force applied at two opposite points, such as u and w , will not produce an electromotive force between the other opposite points v and x .

Fixed resistors 43, 44, and 45, a slide-wire or potential-dividing element 46, and the loop 42 are connected in a closed electrical network, the loop 42 being connected into the network by two opposite points v and x . A source of electromotive force, as a battery 47, is connected to the network at a point between the resistors 44 and 45 and a point between resistor 43 and the loop 42. A galvanometer G' is connected to the network at a point between the loop 42 and the resistor 45,

and through a sliding contact member 48, adapted to be positioned along the slide-wire 46, thereby to balance the network so that there will be no electromotive force applied to the galvanometer. The contact member 48 has associated with it an index or pointer 49, adapted to traverse a graduated scale 50, whereby the position of the contactor corresponding to a condition of balance may be indicated. It will be seen that, with the loop 42 constructed of material having a definite resistance temperature characteristic, the reading of the index 49 on the scale 50 may be made a measure of the temperature of the loop.

If an external circuit I be caused to include the loop 42, by connecting that circuit to the loop at points u and w , it will be apparent, since the four arms of the loop are electrically balanced, that current flowing in the circuit I will not set up any potential difference between the points v and x , by which the loop is connected into the network, and therefore will not tend to cause current to circulate in the network. For the same reason it will further be apparent that completion of a circuit between the points u and w will not disturb the electrical balance of the network as a whole. These conditions make it possible to pass an independent current, which may be alternating and of any frequency, through the loop 42 from the circuit I, without directly disturbing the balance of the system or causing any potential to be applied to the galvanometer.

Since the loop 42 has the property of resistance, the flow of current from an external source will generate heat therein and cause its temperature to be raised; and since the material of the arms of the loop has a temperature coefficient of resistivity, the resistance of the loop as a whole will be changed, unbalancing the network and producing a deflection of the galvanometer G' . The network may be balanced, reducing the deflection of the galvanometer to zero, by positioning the contact member 48 along the slide-wire 46. Thus the position of the index 49 on the scale 50 becomes a measure of the current in the circuit I. The application of such a loop circuit as that described, in a balancing network, for the purpose of measuring electric current is known as a Callendar bridge; and no invention is claimed for the device as thus far set forth.

As the heat generated by the passage of current will be proportional to the product of the square of the current by the resistance of the loop 42, and as the resistance of the loop will vary with its temperature, it follows that the relation between current change in the measured circuit and movement of the contact member 48 to restore balance of the network will not be linear, and that the scale 50 will not be inherently uniform in the spacing of its graduations.

In order to apply the principle of the invention, the slide-wire 46 is proportioned preferably so that the conditions of balance corresponding to the positions of the contacting member 48 at its two extremities will correspond to the minimum and maximum resistance values which will be encountered in the loop 42; i. e. the range of the scale 50 will represent the change in the value of loop resistance corresponding to the range of current to be measured. The slide-wire 46 is formed with a tapered contour as hereinabove set forth, the contour being so formed that potential variations along the slide-wire will follow the same law as the resistance variations of the

loop 42 with change of the measured current; and thus the values of current in the circuit I will be represented by uniformly spaced divisions on the scale 50.

5 While the application of the device as above set forth has been shown as suited to the measurement of current, it will be apparent to those versed in the art that by the use of suitable series resistors and by properly proportioning the several elements of the circuits involved, the method
10 is equally applicable to measurements of electromotive force.

It will further be apparent, since the circuit described performs as an indirect measurement of current through the intermediary of the temperature of the loop 42, that the principle may be
15 used for the measurement of the temperature of this loop, or that the loop may be replaced by a simple resistor having a definite resistance/temperature coefficient, whereupon the principle of
20 the invention may be made applicable to compensation for any source of non-uniformity in the scale of a balancing-type resistance thermometer.

I claim:

In combination: means for producing an electromotive force related to a variable magnitude by a non-linear law, a potentiometer system including a source of slide-wire current and a potential-dividing slide-wire element comprising an elongated support having a contour following a curve representative of a mathematical function of said law with a winding thereon of resistance wire transversely to said support, and a circuit
10 whereby said slide-wire may carry uniformly throughout its length the entire slide-wire current, a movable contact having a circuit including said electromotive force-producing means and contacting successive adjacent points on said
15 slide-wire element connected to and adapted to oppose to said electromotive force in conformity with said law progressively and continuously varied increments of electromotive force per increment of movement of said contact over said slide-
20 wire element.

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