April 26, 1949. DE WITT T. VAN ALEN 2,468,144

RESISTANCE ELEMENT FOR RHEOSTATS AND POTENTIOMETERS

Filed July 2, 1945

Fig. 1

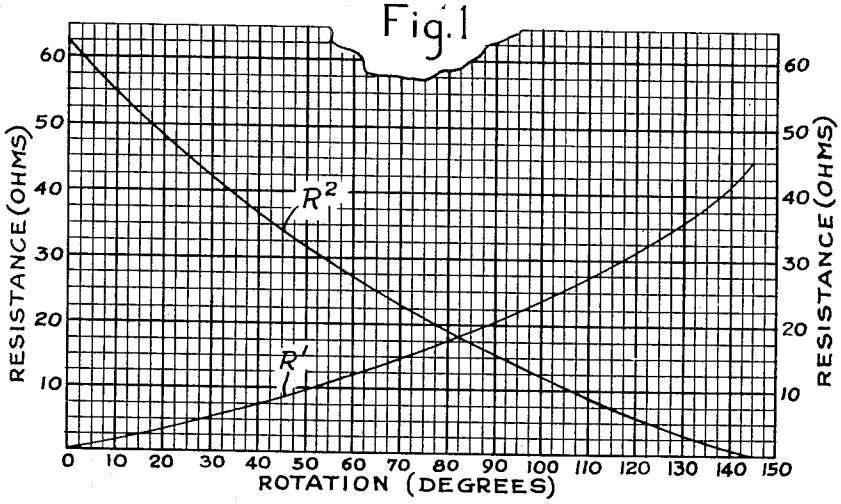


Fig 2

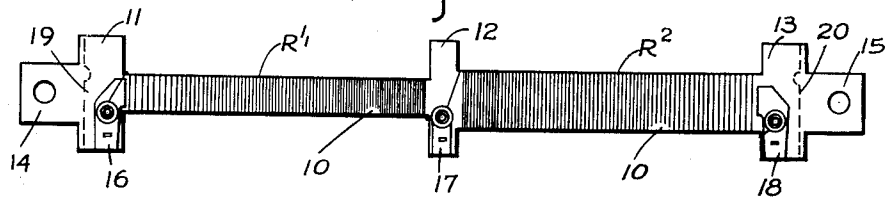


Fig. 3

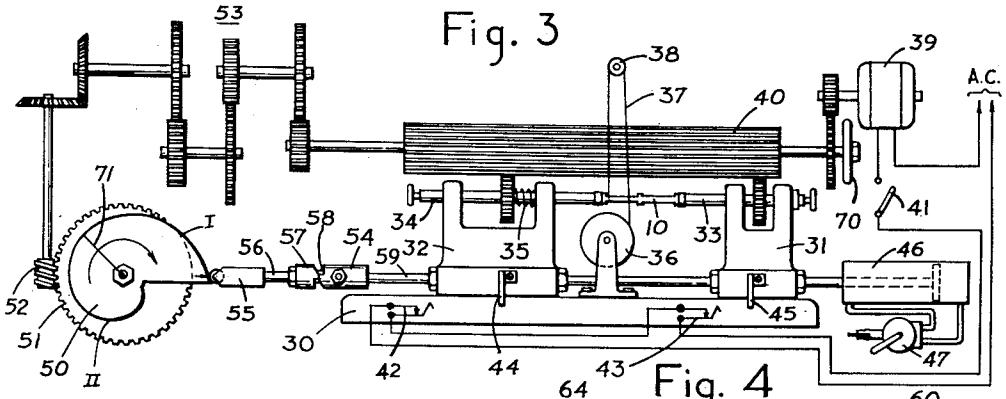


Fig. 4

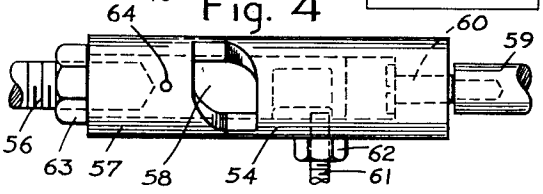
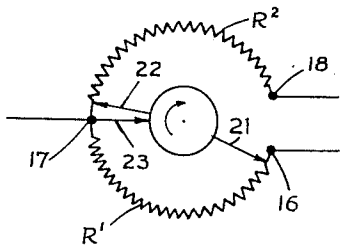


Fig. 5



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RESISTANCE ELEMENT FOR RHEOSTATS AND POTENTIOMETERS

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14 Claims. (Cl. 201—60)

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The present invention relates in general to resistance elements for rheostats and potentiometers, but more in particular to non-linear resistance elements for this purpose which are made by winding resistance wire on an insulating strip or support; and the object of the invention is a new and improved resistance element of this character and a new and improved method and apparatus for winding the same.

A special object of the invention is a resistance element for a potentiometer comprising two windings having related non-linear resistance characteristics, wound on a single strip and having a common terminal.

The various features of the invention will be explained in detail in the ensuing description, reference being had to the accompanying drawing, in which—

Fig. 1 is a graph showing the resistance curves of the two windings of a resistance element embodying the invention;

Fig. 2 is a plan view of the complete resistance element, with terminals attached;

Fig. 3 is a more or less diagrammatic illustration of a winding machine adapted for winding resistance elements such as shown in Fig. 2;

Fig. 4 shows a detail of the winding machine on an enlarged scale, comprising a device for spacing the two windings on the strip; and

Fig. 5 is a diagrammatic illustration of a potentiometer which includes a resistance element such as the one shown in Fig. 2.

Referring to the drawing, Fig. 2, the resistance element therein shown includes a strip made of suitable insulating material such as Bakelite, for example. Strips such as 10 may be punched from sheet stock in a punch press. As shown in the drawing, the strip 10 has relatively wide terminal parts 11 and 13 near the ends, which support the terminals 16 and 18, respectively. There is also a wide part 12 at the center of the strip, carrying the terminal 17 and dividing the strip into two winding spaces for the windings R^1 and R^2. In addition to these parts the strip has perforated end extensions 14 and 15 by means of which it is held in the winding machine during the winding operation.

The winding R^1 is made of suitable resistance wire, such as Advance wire, for example, of uniform diameter, and is wound in the winding space between parts 11 and 12 where the strip is relatively narrow in width. The left hand end of the winding is connected to terminal 16 and the other end to terminal 17. The winding R^2 is continuous with winding R^1 and is located in the

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winding space between parts 12 and 13 where the strip is relatively wide. Terminal 17 serves as the left hand terminal of winding R^2, the other end of which is connected to terminal 18.

The manufacture of the resistance element thus briefly described will be explained more in detail, particularly as regards the winding thereof, but first it may be stated that the resistance element is intended for use in a potentiometer such as is shown diagrammatically in Fig. 5.

The mechanical construction of such potentiometers may vary somewhat, but is generally well known and it will be understood, therefore, that the potentiometer, Fig. 5, includes a cylindrical casing, preferably of insulating material, in which the resistance element is mounted. For this purpose the strip 10 is cut off at both ends along the dotted lines 19 and 20 and is bent into a circle so that it can be inserted in the casing. It is held in place by a small screw passed through the hole formed by the semi-circular notches in the abutting ends.

The potentiometer also includes a shaft rotatably supported on the casing and carrying the two wipers 21 and 22 which cooperate with the windings R^1 and R^2, respectively. In addition, means is provided, represented by wiper 23, for maintaining connection between terminal 17 and the wipers 21 and 22. The external circuit connections are made to the terminals 16, 17 and 18, as indicated.

The resistance characteristics of the two windings R^1 and R^2 are shown by the corresponding curves in Fig. 1, which for convenience are given the same reference characters. These curves are made by plotting the resistance in ohms against the rotation of the wipers in degrees. In the case of winding R^1 the curve shows that when the wipers are in zero position the resistance is zero and that the resistance increases as the wipers are rotated until a maximum resistance of about 45 ohms is reached when the wipers have been rotated 145 degrees. The resistance is measured between terminals 16 and 17. As regards the winding R^2, the resistance with the wipers in zero position, measured between terminals 17 and 18, is a maximum and amounts to about 62½ ohms. The resistance decreases with rotation of the wipers and has the value of zero, or substantially zero, after a rotation of 145 degrees.

It will be noted that the curves are not straight lines. The non-linear resistance characteristics are obtained by means of a varying spacing of the turns of the windings. In the case of winding

R^1 the turns have a maximum spacing at the left hand end of the winding adjacent terminal **16** and the spacing progressively decreases toward the other end. The turns of winding R^2 on the other hand have the smallest spacing at the left hand end adjacent terminal **17** and the spacing increases progressively from left to right, the largest spacing being used adjacent terminal **18**.

The resistance element may be wound on a winding machine such as is disclosed in the pending application of Gilman et al., Serial No. 563,522, filed Nov. 15, 1944. This winding machine is shown diagrammatically in Fig. 3, which includes enough of the details so that the operation of the machine can be readily understood.

Describing the machine briefly, it comprises a bed **30** on which the so-called headstock **31** and tailstock **32** are slidably mounted. These parts rotatably support the two spindles **33** and **34** which are provided with collets for holding a strip such as **10** for winding. The strip is held under tension by the spring **35** and also has a rotating support (not shown) at the point where the winding is applied.

The resistance wire **37** from which the winding is formed is carried on a spool **36** from which it passes to the pulley **38** and thence to the strip **10**. The pulley **38** is part of an automatic tensioning device (not shown) which maintains the proper tension on the wire **37** by regulating the rate at which it is fed from spool **36**. The wire is wound on the strip **10** by rotating the strip, which is accomplished by rotating the spindles **33** and **34**. Power is supplied by the motor **39**. The motor is coupled to the spindles by suitable means such as the gearing shown, including the wide faced pinion **40** which meshes with gears on the spindles.

The circuit of the motor is controlled by a manually operated switch **41** and by two switches **42** and **43** which are operated by the cams **44** and **45**, respectively.

The headstock and tailstock assembly is moved on the bed **30** by compressed air. The concerned apparatus includes the cylinder **46** having a piston which is connected to the headstock **31**. The admission of air to the cylinder **46** is controlled by a valve **47**. Air may be admitted to either end of the cylinder and exhausted from the other end at the same time, whereby the headstock and tailstock assembly may be moved on the bed in either direction.

The movement of the headstock and tailstock assembly to the left is used during the winding operation to move the strip **10** past the point where the winding is applied and thus space the turns of the winding on the strip. This movement is controlled by the cam **50** which is driven from the shaft on which pinion **40** is mounted by suitable gearing including the worm gear **51**, the worm **52**, and the interchangeable gears **53**. The cam **50** is thus driven in timed relation to the spindles **33** and **34** and the strip **10** supported thereby.

The headstock and tailstock assembly may be shifted to the left independent of cam **50** by means of a rotatable sleeve **54** which forms part of the connection between the tailstock **32** and the cam follower **55**. This independent movement spaces winding R^2 from winding R^1 and the distance traveled corresponds to the length of part **12** of strip **10**.

The mechanism referred to in the preceding paragraph may be explained briefly in connection with Fig. 4. The rod **56** is threaded into the short

larger diameter rod **58** and is secured by the locknut **63**. The sleeve **57** is fixed on rod **58** where it is held by a press fit or by a pin **64**. The sleeve **54** is rotatable on rod **58** and is rotatably secured to the rod **59** by means of the shoulder screw **60**. The sleeve **54** is rotated by means of the rod **61** which is threaded into a tapped hole in the side of the sleeve and held by a locknut **62**. The end of rod **61** extends through the sleeve and into a channel formed in rod **58** which prevents the sleeve **54** from being pulled off rod **58**.

In the position in which the sleeve **54** is shown in the drawing the projections formed at the end thereof are aligned with corresponding projections at the end of sleeve **57** and the tailstock **32** is separated from the cam follower **55** by the maximum distance. When the sleeve **54** is rotated in a clockwise direction at a time when the headstock and tailstock assembly is being urged toward the left, the projections at the end of each sleeve enter recesses at the end of the other sleeve and the distance is reduced by an amount equal to the depth of these recesses. Each recess has a sloping cam surface as shown so that sleeve **54** can be easily restored by means of the rod **61**.

The winding operation is much the same as described in the Gilman et al. application hereinbefore referred to and for this reason and because of the omission from Fig. 3 of a number of parts not concerned with the invention the operation will not be described in great detail.

It may be assumed that the winding machine is in the position shown in the drawing. The arrow on cam **50**, which marks the starting position, is aligned with the roller on cam follower **55** and the valve **47** is in its left hand position, whereby air is admitted to the right hand end of cylinder **46** and the headstock and tailstock assembly is urged toward the left, holding the roller on the cam follower **55** against the cam **50**. The end of wire **37** is secured under a clip on the collet on spindle **34** and is started onto the strip by hand, the spindles being rotated for this purpose by means of the hand wheel **70**. In this connection it should be mentioned that the strip **10** is preferably wound before the terminals are attached, although this is not strictly necessary.

Everything being in readiness, the operator starts the machine by closing the switch **41**. The motor **39** accordingly starts to run and rotates the spindles **33** and **34**, thereby winding the wire **37** on the strip **10** in successive turns which are spaced apart along the strip by the cam **50**, also driven by the motor **39**. This operation will be readily understood from the drawing, where it will be seen that rotation of the cam **50** in a clockwise direction will permit the headstock and tailstock assembly to move gradually to the left in response to the power supplied by the compressed air in cylinder **46**. The shape of the cam is such that the spacing of the turns decreases as the winding proceeds. It will be understood also that the tensioning apparatus responds to the demand for wire and controls the rotation of spool **36** at a rate which maintains the proper tension in the wire. The tensioning apparatus and also a device for laying the wire accurately on the strip are shown and described in the Gilman et al. application previously referred to.

The winding operation continues in this manner until the winding reaches or very nearly reaches the part **12** of the strip **10**, whereupon the cam **45** opens the switch **43** and stops the motor **39**. The operator now opens the switch **41** and then winds one or more turns on by hand,

if necessary to complete the winding. This is winding R^1. The sleeve **54** may now be rotated, which moves the strip **10** to the left and brings the beginning of the second winding space opposite the mechanism for delivering the wire to the strip. There is a hole in the strip for the rivet which will be used to attach terminal **17** and after inserting a wooden peg in this hole the operator guides the wire around the peg and onto the wide part of the strip with one hand while rotating the handwheel **70** slowly with the other hand. The apparatus is now ready to put on winding R^2.

The movement of the headstock and tailstock assembly to the left responsive to the rotation of sleeve **54** moved the cam **45** past the switch **43**, which is now closed, therefore. Accordingly, when the operator recloses switch **41** the motor **39** starts to run again and the winding operation is resumed. It continues as previously described, except that now the cam **50** produces an increasing spacing of the turns, until the winding space is filled or very nearly filled, when the cam **44** opens the switch **42** and stops the motor **39** again. The operator now opens switch **41** and if the winding space is not entirely filled she adds one or more turns by hand as before. This completes the winding R^2. The strip **10** may now be removed from the machine. The free ends of the windings R^1 and R^2 are secured to the strip in some suitable manner, as by looping them through the holes in the end of the strip.

The wound strips are transferred to another working stage where the terminals are attached and the end extensions **14** and **15** are cut off as mentioned hereinbefore.

Returning to the winding machine the operator prepares for winding another strip by rotating the sleeve **54** back to its original position and by moving the handle of valve **47** to its right hand position. The latter operation opens the right hand end of cylinder **46** to the atmosphere and admits compressed air to the left hand end, resulting in the movement of the headstock and tailstock assembly to the right as far as it will go. The end of the cylinder may be used as a stop and will arrest the motion of the parts in a position somewhat to the right of the position in which they appear in the drawing. The switch **41** is now closed again and the machine is allowed to run far enough to advance the cam **50** to starting position, when the switch is opened. The handle of valve **47** is then moved to its left hand position, whereupon the headstock and tailstock assembly is moved to the left until the motion is arrested by the cam **50**. Another strip such as **10** may now be inserted and wound in the same way as described.

In the foregoing the resistance element shown in Fig. 2 has been described, likewise the winding machine and the mechanical operations involved in winding the two windings R^1 and R^2 on the strip. It has also been pointed out that the strip has winding spaces which differ in width and the fact that the spacing of the turns decreases from left to right in winding R^1 and increases from left to right in winding R^2 has been mentioned. This is not sufficient to show, however, that the resistance characteristics of the windings R^1 and R^2 of the completed resistance element conform to the curves in Fig. 1 and some further explanation will therefore be necessary in order to show how those factors which affect the curves are calculated in advance so that resistance elements may be manufactured which conform accurately to specifications.

The values which may be assumed to be given are the length of the strip, which is determined by the inside circumference of the potentiometer casing, the number of degrees of rotation of the wipers, the total resistance of each winding, and curves such as are shown in Fig. 1 which show how the resistances of the windings vary with degrees of rotation. The resistance at a number of points on each curve may be exactly specified. The approximate size of the resistance wire may also be given or may be determined from the value of the current that must be carried.

From the length of the strip, which corresponds to 360 degrees, and the number of degrees of rotation the length of each of the two winding spaces in inches may be calculated. These winding spaces are equal in length.

The winding space for winding R^1 is now arbitrarily divided into 20 seconds, each having a length equal to $\frac{1}{20}$ of the total length of the winding space.

A table is then prepared in which the numbers of the sections from 1 to 20 are entered in a vertical column and the resistances at the ends of the sections are entered in a second vertical column. These resistance values are taken from the curve, Fig. 1. If the rotation is 145 degrees, for example, the length of each section in degrees will be 7.25 degrees. The end of the first section may be indicated by a point 7.25 on the X axis, the end of the second section by a point 14.5, and so on. These points having been marked on the graph, the corresponding resistances can be read off on the Y axis in the usual manner. The next operation is to subtract each resistance value from the next higher value and thus obtain the resistance of each individual section. These individual section resistances are entered in a third column.

It has been found convenient to make use of a quantity Q which is defined as the ratio of the space between turns to the diameter of the wire; that is, Q is equal to the space between turns in mils divided by the diameter of the wire in mils. Then, if the diameter of the wire in mils is represented by D,

QD = space between turns, and
$D(1+Q)$ = total space occupied by one turn

Now, if S is equal to the length of one section of the winding space for R^1 in inches, and N is equal to the number of turns in the section,

$$(1) \qquad N=\frac{10^3 S}{D(1+Q)}$$

Continuing, we may let L equal the length of one turn, and L_s the total length of wire in one section, in inches, and write the equation

$$(2) \qquad L_s=LN$$

Substituting in Equation (2) the value of N from Equation (1),

$$(3) \qquad L_s=\frac{10^3 SL}{D(1+Q)}$$

Now if R equals the resistance in ohms, and K is equal to the specific resistance of the wire in ohms per circular mil foot, the equation for resistance can be written as

$$(4) \qquad R=\frac{KL_s}{12D^2}$$

Substituting in Equation (4) the value of L_s from Equation (3),

$$(5) \qquad R=\frac{\frac{10^3 KSL}{D(1+Q)}}{12D^2}=\frac{10^3 KSL}{12D^3(1+Q)}=83.33\frac{KSL}{D^3(1+Q)}$$

From Equation (5) we can write the equations for L, D and Q as follows:

$$L=\frac{RD^3(1-Q)}{83.33KS} \quad (6)$$

$$D=4.368\sqrt[3]{\frac{KSL}{R(1+Q)}} \quad (7)$$

$$Q=\frac{83.33KSL}{RD^3}-1 \quad (8)$$

Equation 6 can now be used to ascertain the value of L, or the length of one turn of the winding R^1. In this connection it may be pointed out that the equation is applied specifically to the last section of the winding where the quantity Q has the smallest value. It will be clear that for this section a value of Q can be assumed which approaches fairly close to the smallest value that can be used satisfactorily. This value has been found to be about .15, and it will therefore be satisfactory to assume a minimum value for Q of .25. The value of R is taken from the table which has been prepared, which gives the resistance of each section, as previously explained. It has been assumed that the value of D is given, at least approximately. The value of K is ascertained from a standard resistance table, and the value of S has already been calculated, being 1/20 of the length of the winding space.

After substituting the known or assumed values above referred to in Equation (6), it is solved for L and the result is considered from the standpoint of whether or not the strip width indicated is practicable or within permissible limits. The strip width is roughly about one-half the turn length. If the strip width thus estimated is too great a smaller diameter wire will have to be used, while if the strip width is too small a larger wire must be used. In either case one or more different values of D will have to be assumed and the solution of Equation (6) will be repeated until the result indicates a strip width which is all right.

Alternatively, a desired strip width and corresponding turn length L can be assumed and Equation (7) can be solved for D, as will readily be understood.

The values of D and L having been tentatively settled on, as described in the foregoing, Equation (8) is employed in order to ascertain the value of Q in the first section of the winding, where the spacing between turns is the greatest. The known or ascertained values are substituted in the equation, using the value of R for the first section as shown by the prepared table, and the equation is solved for Q. This is a check on the possibility of meeting the requirements of the resistance curve R^1 by a varying spacing of the turns of the winding. The upper limit of the value of Q is about 4, and if the value obtained by solution of Equation (8) is appreciably greater than this value, this fact indicates that it is impracticable to make a winding having the desired resistance curve by a varying spacing of the turns alone. A maximum value of Q of about 3 is very satisfactory and it will be clear that in any practicable case the value will be somewhere between the allowable maximum and the minimum of .25 which has been assumed for the last section.

A table is now prepared for winding R^2 similar to the table which was prepared for winding R^1. Also, following the same procedure that was used in connection with winding R^1, the value of L for winding R^2 is ascertained. Since the same

wire is to be used and since winding R^2 has a greater total resistance it is clear that L will be greater in winding R^2 than in winding R^1. This means a wider strip, which was of course foreseen when the width of the strip for winding R^1 was determined. It may be assumed therefore that a low enough value for the width of the strip at R^1 has been selected so that the width of the strip at R^2 will not exceed the allowable limit. If not, it may be possible to reduce the width of the strip at winding R^1 by reducing D, or the wire size, which will reduce the strip width at winding R^2.

Equation (8) may now be used to check the value of Q at the last section of winding R^2.

The value of D and the values of L for both windings having been finally determined, the exact width of the strip for each winding is calculated as accurately as possible from the corresponding value of L and the measured thickness of the material. Other factors such as size of the wire and the winding tension, which are known to affect the result, may be taken into consideration. The strip widths as thus determined are checked empirically by cutting strips to the exact dimensions, winding a measured length of wire thereon under the proper winding tension, and counting the number of turns in the measured length of wire. A wire having the diameter D is used of course and the measured length may be a section extending between two marks the distance between which is equal to 100 L. If the strip width is correct 100 turns should be obtained and if the result differs appreciably a correction in the strip width will have to be made.

The resistance per turn in winding R^1 may now be found by substituting L for L_s in Equation (4) and solving for R. The number of turns N^1 in winding R^1 may then be found by dividing the total resistance of winding R^1 by the resistance per turn.

The number of turns N^2 in winding R^2 is found in the same way.

The next step is to determine the gear ratio G, which is a number obtained by dividing the number of spindle rotations, or the number of turns in windings R^1 and R^2, by the number of rotations of the cam 60. Assuming that 335 degrees of the cam are to be used, the cam makes

$$\frac{335}{360}$$

of one rotation and the gear ratio can be found by means of the equation

$$G=\frac{N^1+N^2}{\frac{335}{360}}$$

The next and final operation is to calculate the contour of the cam 50. The useful part of the cam, equal to 335 degrees, may be considered as being divided into two parts, I and II, by the radial line 71, part I being used to control the spacing of winding R^1 while part II is used to control the spacing of winding R^2. Since the winding spaces for R^1 and R^2 are equal in length the cam rise in part II is the same as in part I and in each case is equal to the length of the winding space. The number of degrees in the two parts of the cam, however, will not be the same unless the number of turns in the two windings is the same, which is usually not the case and is not true as regards the windings under consideration.

Considering part I of the cam now, this part may be divided into 20 sections corresponding to the 20 sections into which the winding R^1 was divided and as to which the resistance data has been tabulated. Each cam section will have the same rise, equal to 1/20 of the total rise on part I. The angular length of each cam section in degrees will depend upon the number of turns N, or the resistance R, of the corresponding section of the winding R^1. The angular length may be referred to as the cam angle and represented by the symbol A. Since the resistances of the winding sections have been tabulated rather than the number of turns therein, the calculation of the cam angle A requires an equation for A in terms of R. The derivation of this equation will therefore be explained.

It will be clear that since the cam is geared to the spindles the cam angle A is a function of N, or the number of turns. This relation may be expressed by the equation

$$A=\frac{360N}{G} \tag{9}$$

Solving Equation (9) for N, we obtain the equation

$$N=\frac{GA}{360} \tag{10}$$

Substituting the value of N as given by Equation (10) for N in Equation (2) we obtain

$$L_s=\frac{LGA}{360} \tag{11}$$

Then, substituting the value of L_s as given in Equation (11) for L_s in Equation (4) we get the equation

$$R=\frac{K\left(\frac{LGA}{360}\right)}{12D^2}=\frac{KLGA}{4320D^2} \tag{12}$$

Solving Equation (12) for A, we obtain the equation

$$A=\frac{4320D^2R}{KLG} \tag{13}$$

Now for any given winding the quantity

$$\frac{4320D^2}{KLG}$$

is a constant, and if this constant is represented by the symbol C, Equation (13) can be rewritten as

$$A=CR \tag{14}$$

The value of the constant C can be determined readily, since the values of D, K, L, and G are known. The actual value of C may then be substituted for C in Equation (14).

The cam constant C having been determined, the number of degrees in each cam section can be found by means of Equation (14), that is, by multiplying the resistance of the corresponding winding section, as shown by the table hereinbefore mentioned, by the cam constant. The results may be tabulated by adding another column to the table. The values in this cam angle column together with the known value of the rise per section enable 20 points on the cam contour to be fixed, in addition to the starting point, and the cam is laid out by constructing a smooth curve which extends through these points.

Part II of the cam is calculated and laid out in the same way and is a continuation of part I. The cam constant for part II is first figured

from Equation (13) and will be different from the cam constant for part I because the value of L is different. Then the number of degrees in each section of part II is found by reference to the resistances of the corresponding sections of winding R^2 as tabulated and by use of the cam constant for part II of the cam, as described in connection with part I.

The results can be checked by adding together the number of degrees in all the cam sections of parts I and II. The sum should be equal to 335 degrees.

The foregoing shows how the width of the strip 10 at the two winding spaces is determined and also shows how the cam 50 is designed. The calculation of the gear ratio has also been explained and it will be understood that the provision of interchangeable gears such as 53 enable the winding machine to be set up in accordance therewith. Assuming that the instructions are observed, resistance elements such as shown in Fig. 2 may be wound as described with the assurance that the resistance curves of the windings R^1 and R^2 will conform closely to the desired resistance curves, as shown in Fig. 1, for example.

The chief factor which affects the accuracy of the potentiometer is the resistance of the wire, which may vary somewhat due to a variation in the diameter of the wire and occasionally also due to a variation in specific resistivity. It is good practice, therefore, when great accuracy is a prime consideration, to measure the resistance of a sample of wire from each spool before the wire is used.

In case the resistance of a certain spool of wire is found to differ from the assumed value, and assuming that the difference is not too great, it can be compensated for by a change in the gear ratio. Suppose, for example, that the resistance of the wire is found to be less than the normal value on which the calculations have been based. Now the cam 50 rotates through an exact predetermined angular distance for each winding and since the cam and spindles are geared together each winding has an exact predetermined number of turns. The turn length L is fixed by the width of the strip and it follows, therefore, that if the low resistance wire is used without any change in the winding machine the total resistance of the windings will be lower than specified. A change in the gear ratio G may be made, however, which will cause the number of turns in the windings to be increased sufficiently to compensate for the low resistance of the wire and thus maintain the total resistance of the windings up to standard.

The change in gear ratio required can be calculated from the number of turns which have to be added (or subtracted if the wire resistance is too high) and the number of turns can be calculated from the ascertained value by which the actual resistance of the wire departs from its correct or assumed resistance. In this way it is possible to use commercial wire with the usual tolerances as to resistance and still maintain a high degree of accuracy in the resistance elements made from such wire.

A method which has been successfully used in practice involves the use of an equation for the gear ratio G in terms of the resistance R of a unit length of wire. This will be explained briefly.

The value of the cam constant C has been determined from the equation

$$C=\frac{4320D^2}{KLG} \tag{15}$$

From Equation (15) we can write the equation

$$CG=\frac{4320D^2}{KL}=360\frac{12D^2}{KL} \tag{16}$$

As mentioned previously the equation for the resistance R, see Equation (4), is

$$R=\frac{KL}{12D^2}, \tag{17}$$

or

$$\frac{1}{R}=\frac{12D^2}{KL} \tag{18}$$

Now, substituting the value of the right hand term of Equation (18) in Equation (16), we can rewrite the latter equation as

$$CG=360\frac{1}{R} \tag{19}$$

and from Equation (19) we can write an equation for the gear ratio G as

$$G=\frac{360}{CR} \tag{20}$$

In Equation (20), R is the resistance of the wire in ohms per turn. This value is known, or can be readily calculated, from the measured resistance of the wire, and since the value of the cam constant C is also known, these values may be substituted in Equation (20) which is then solved for G to give the required gear ratio. The equation may be applied to either winding R^1 or winding R^2, for the product CR is the same in the case of both windings.

The solution of Equation (20) may be regarded as involving the operation of dividing the constant

$$\frac{360}{C}$$

by the resistance per turn, and the equation shows therefore that the gear ratio G is equal to a constant divided by the resistance per unit length. Since it is not convenient to measure the resistance of one turn of wire directly it is preferable to select a larger unit of length, three feet, for example, and calculate the constant in accordance therewith.

It will be understood that the invention may be used in the manufacture of non-linear resistance elements having a single winding as well as in the manufacture of the more complicated resistance element shown in the drawing. Due to the somewhat limited range for the quantity Q, the turn spacing factor, the invention is not universally applicable but in the field where it can be used it is highly desirable since it makes it possible to economically manufacture non-linear resistance elements which are extremely accurate and reliable.

The invention having been described, that which is new and for which the protection of Letters Patent is desired will be pointed out in the appended claims.

I claim:

1. A non-linear resistance element having a predetermined total resistance, comprising an insulating support having a winding space of uniform cross-section and fixed predetermined length, and a winding of resistance wire in said space, said wire being of uniform diameter, said winding comprising spaced turns depending in number on the resistance of said wire, and the spacing of said turns varying from one end of the winding to the other in accordance with a given non-linear resistance curve, and the resistance of said wire being so selected that said turns spaced as set forth exactly fill said winding space.

2. A resistance element comprising a strip of insulating material of uniform thickness, said strip having a winding section of uniform width and a second winding section of uniform width which is greater than the width of the first section, a winding of uniform diameter resistance wire on the first section, the turns of said winding having a spacing which decreases in one direction along the strip, and a winding of uniform diameter resistance wire on said second section, the spacing of the turns of said second winding having a spacing which decreases in the opposite direction along the strip.

3. A resistance element comprising a strip of insulating material having two winding sections disposed end to end, one of said winding sections being wider than the other, and a continuous unidirectional winding of uniform diameter resistance wire on said winding sections, the turns of that portion of the winding which is on the first winding section having a decreasing spacing in one direction, and the turns, of that portion of the winding which is on the second winding section having a decreasing spacing in the opposite direction.

4. A resistance element comprising a strip of insulating material of uniform thickness, a terminal near one end of said strip, a second terminal near the other end of said strip, a common terminal between the first and second terminals, a winding section of uniform width between said first terminal and said common terminal, a second winding section of different uniform width between said common terminal and said second terminal, a winding of uniform diameter resistance wire on said first winding section having one end connected to said first terminal and the other end connected to said common terminal, and a winding of uniform diameter resistance wire on said second winding section having one end connected to said common terminal and the other end connected to said second terminal, the turns of said windings having varying spacings which correspond to two predetermined curves, respectively.

5. The method of winding a continuous resistance wire on a strip of insulating material to form a two section resistance element, which consists in rotating the strip to wind the wire thereon, feeding the wire to the strip at a fixed point, moving the strip longitudinally past said point at a rate bearing a predetermined relation to the rotational speed of the strip to space the turns of the winding, imparting an independent motion to the strip when the first section is completed to space the second section of the winding from the first, and again moving the strip at a rate bearing a predetermined relation to its rotational speed to space the turns of the second section of the winding.

6. In a winding machine for winding two section resistance elements, a device for holding and rotating a strip of material to wind a resistance wire thereon, means for gradually moving said device relative to the point where the wire is delivered to the strip to space the turns of the winding, and additional means for quickly moving said device relative to said point to divide said winding into two sections.

7. In a winding machine for winding resistance wire on a strip to make a two section resistance element, a device for holding and rotating said strip to wind said wire thereon, means including a cam geared to said device for moving said strip to space the turns of the winding, means including a switch for stopping the machine upon completion of the first section of the winding, and means independent of said cam for moving said strip to space the second section from the first, said independent movement being effective to reclose said switch preparatory to winding the second section.

8. In a coil winding machine, a device for holding and rotating a strip of material to wind a coil thereon in successive turns, and turn spacing means comprising a cam driven in timed relation to the rotation of said strip, a cam follower, a connection between said follower and said device, means tending to move said device in the proper direction to hold said follower against said cam, and means included in said connection for bringing about a movement of said device independent of said cam and follower.

9. The method of winding resistance elements from wires which vary in resistance, which consists in rotating successive strips of material to wind said wires thereon, in imparting longitudinal movement for the same distance to each strip as it is wound to space the turns of the winding, in measuring the resistance of said wires prior to winding thereof, and varying the number of turns on said strips in accordance with the measured resistance of the wires with which they are wound by varying the relation between the rotational speeds of the strips and their rate of longitudinal movement.

10. The method of winding a resistance wire on a strip of material to form a resistance element having a predetermined resistance, which consists in rotating said strip to wind said wire thereon, in moving said strip longitudinally past the point where the wire is delivered to the strip to cause the wire to be wound in spaced turns, and in regulating the speed at which the strip is moved to a rate which is predetermined in accordance with the resistance of said wire.

11. The method of winding resistance elements from batches of wire which vary in resistance, which consists in rotating successive strips of material to wind said wire thereon, in imparting longitudinal movement for the same distance to each strip as it is wound to space the turns of the winding, in measuring the resistance of the wire in each batch, and in fixing the number of turns wound on each strip by regulating its rate of movement in accordance with the measured resistance of the wire in the batch from which

it is wound, whereby the said resistance elements all have the same resistance.

12. A resistance element having a predetermined total resistance, said element comprising a strip of insulating material having a winding space of uniform cross section, and a winding of uniform diameter resistance wire in said winding space, the turns of said winding having a spacing which has a selected value at one end of the winding and which changes in accordance with a desired non-linear resistance curve to a different value at the other end of the winding, the width of said strip and the resistance of said wire being so related to the said total resistance that the number of turns required to produce said total resistance fill said winding space when wound therein with the turns spaced as set forth.

13. A resistance element having a predetermined total resistance, said element comprising a strip of insulating material having a winding space of uniform cross section from end to end, and a winding of uniform diameter resistance wire in said winding space, the turns of said winding having a varying spacing which progressively increases from one end of the winding to the other in accordance with a desired non-linear resistance curve, the width of said strip and the size of said wire being so related to the length of said winding space that the number of turns required to fill the same with the said turn spacing gives the winding the said total resistance.

14. A resistance element having a fixed total resistance and a non-linear resistance curve, said element comprising a strip of insulating material providing a winding space of uniform width, a winding of uniform diameter resistance wire in said winding space, said winding having a number of turns so related to the turn length and the unit wire resistance that the winding has said total resistance, the said turns being distributed in said winding space with a varying spacing in accordance with said resistance curve, and said curve being so close to a straight line that the maximum and minimum values of the turn spacing lie within a predetermined limited range.

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