

June 20, 1961

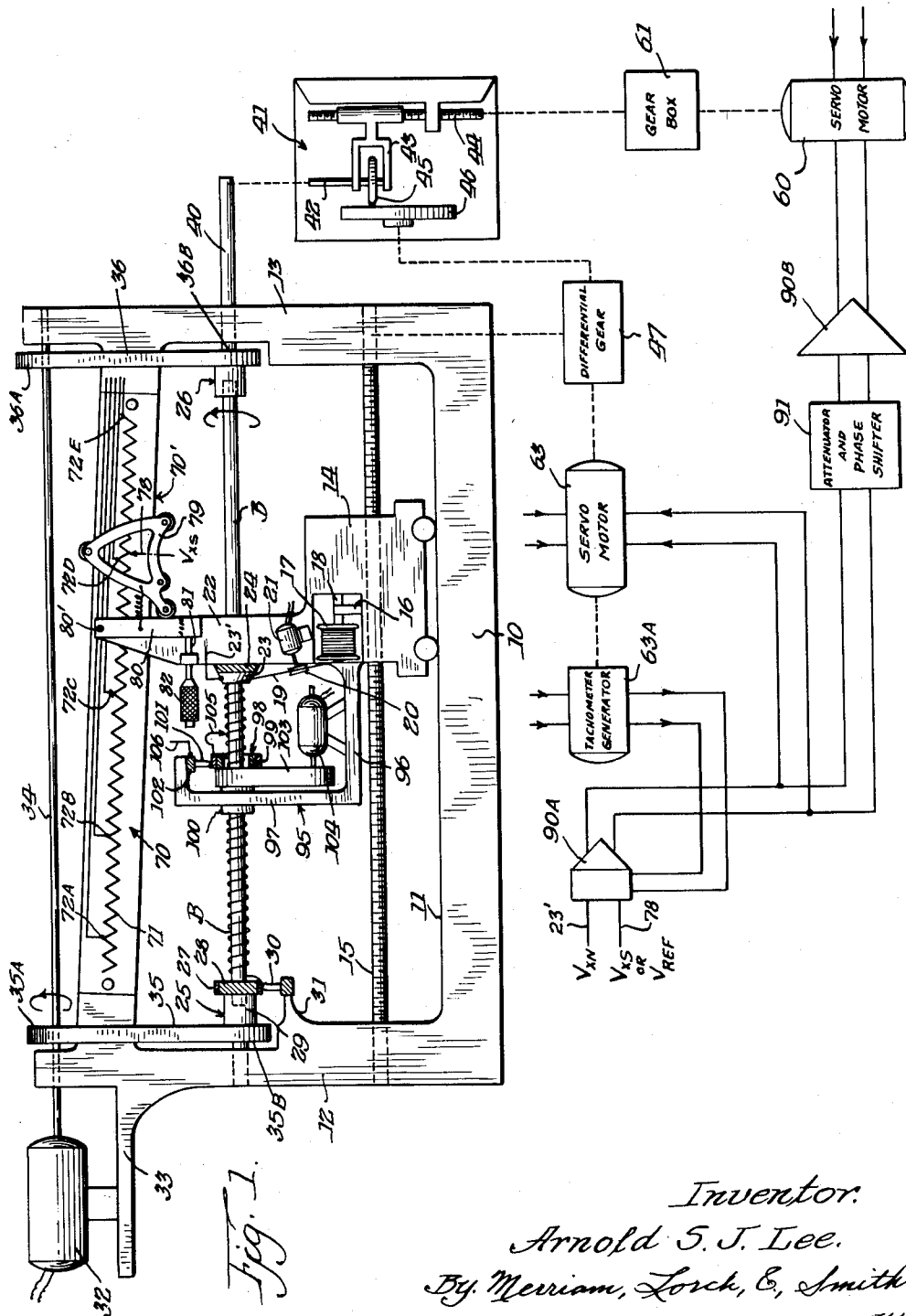
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2,989,256

METHOD AND APPARATUS FOR MANUFACTURING POTENTIOMETER RESISTORS

Filed April 15, 1959

5 Sheets-Sheet 1



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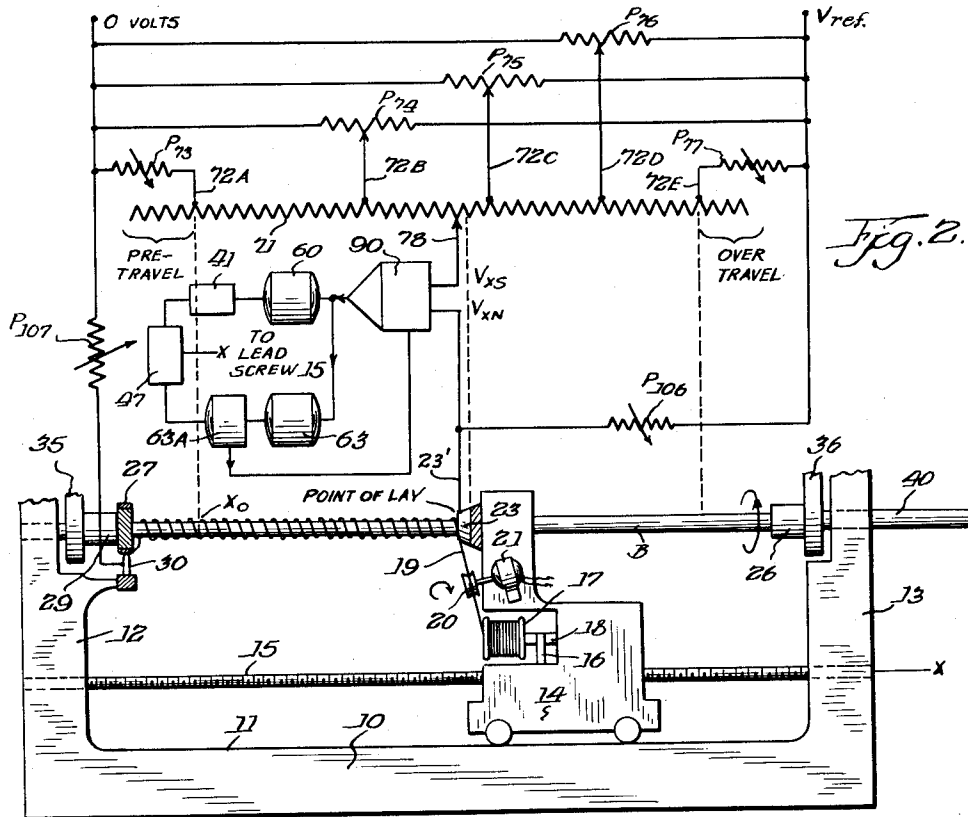
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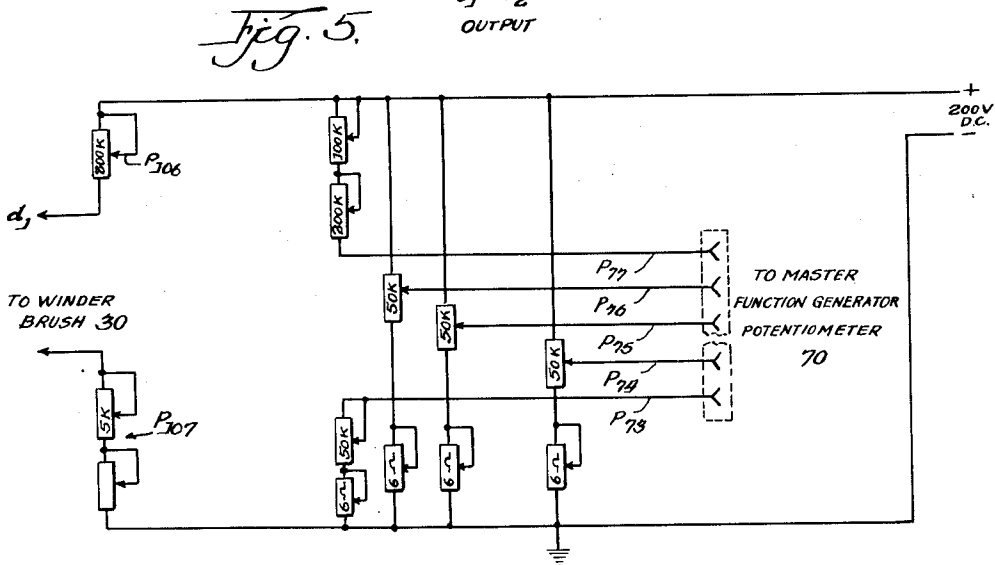
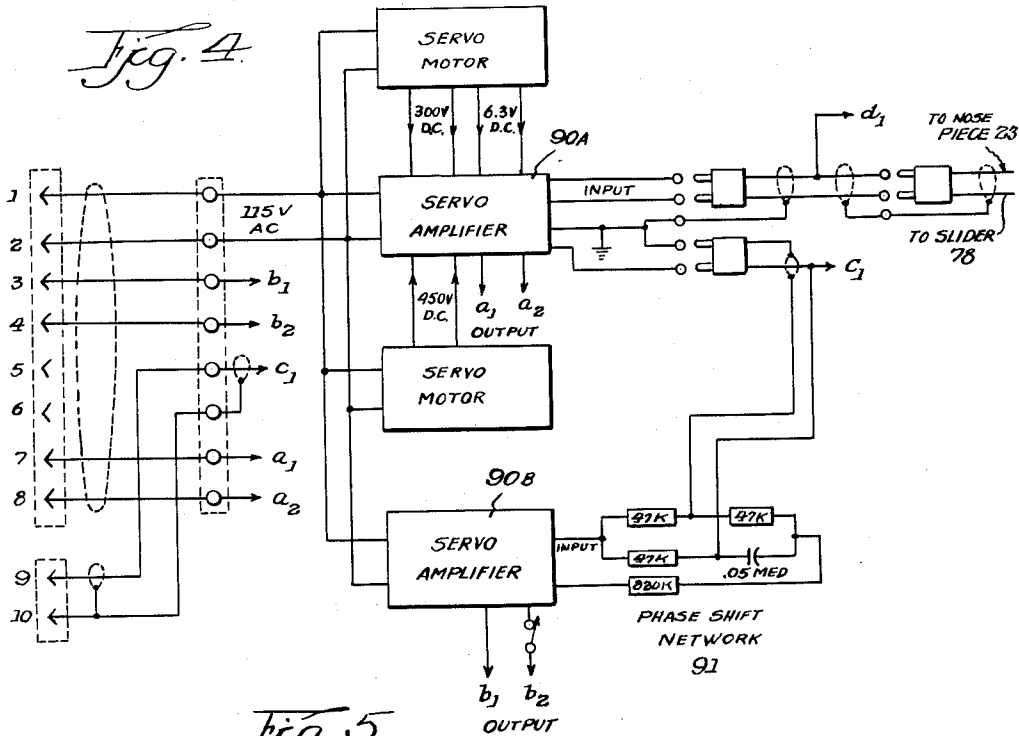
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METHOD AND APPARATUS FOR MANUFACTURING POTENTIOMETER RESISTORS

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5 Sheets-Sheet 3



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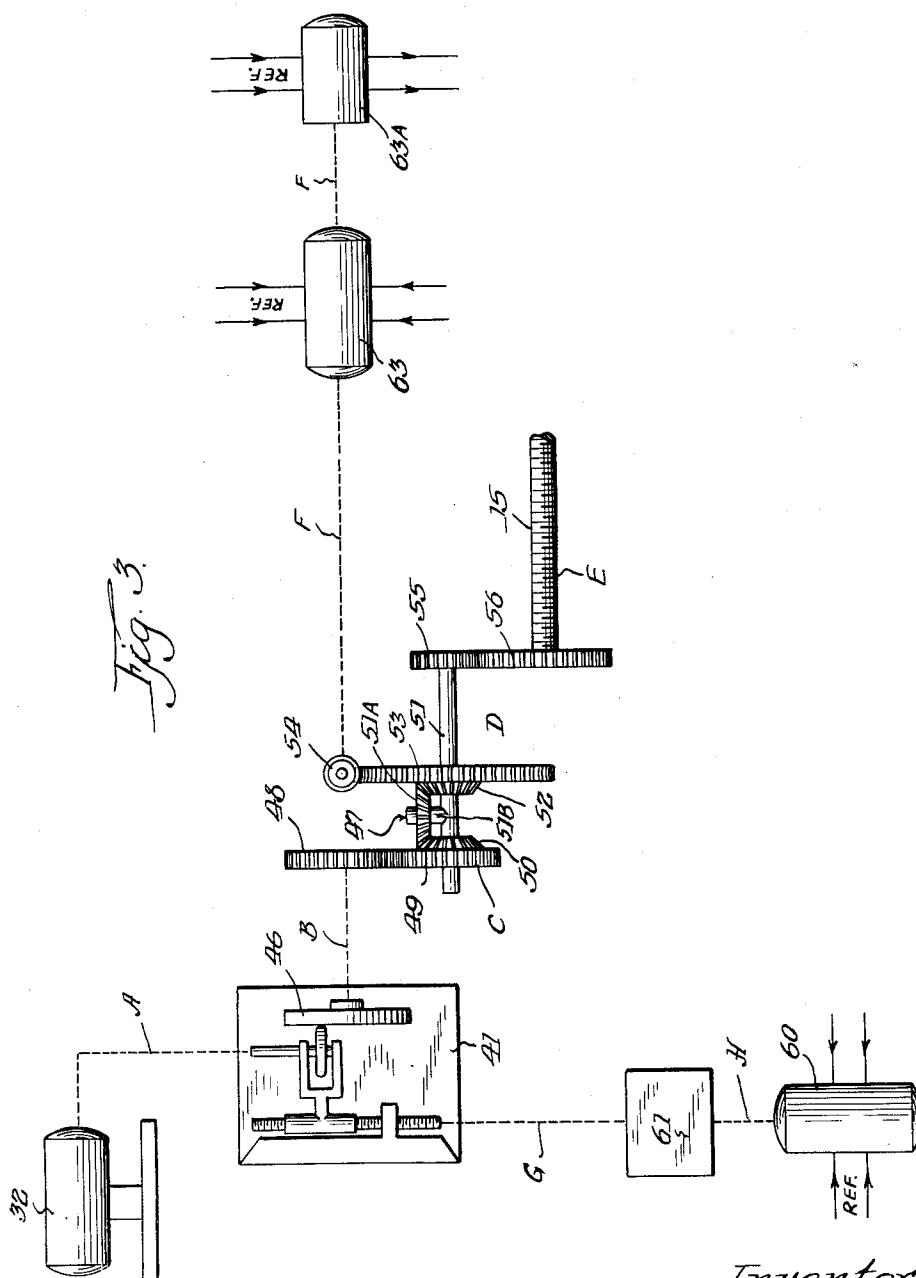
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5 Sheets-Sheet 4



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METHOD AND APPARATUS FOR MANUFACTURING POTENTIOMETER RESISTORS

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Fig. 8.

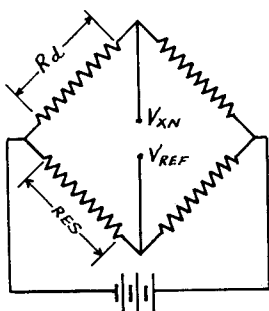


Fig. 9.

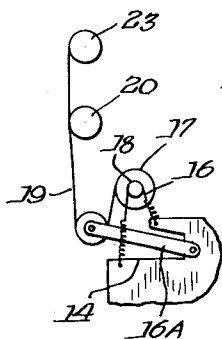


Fig. 10.

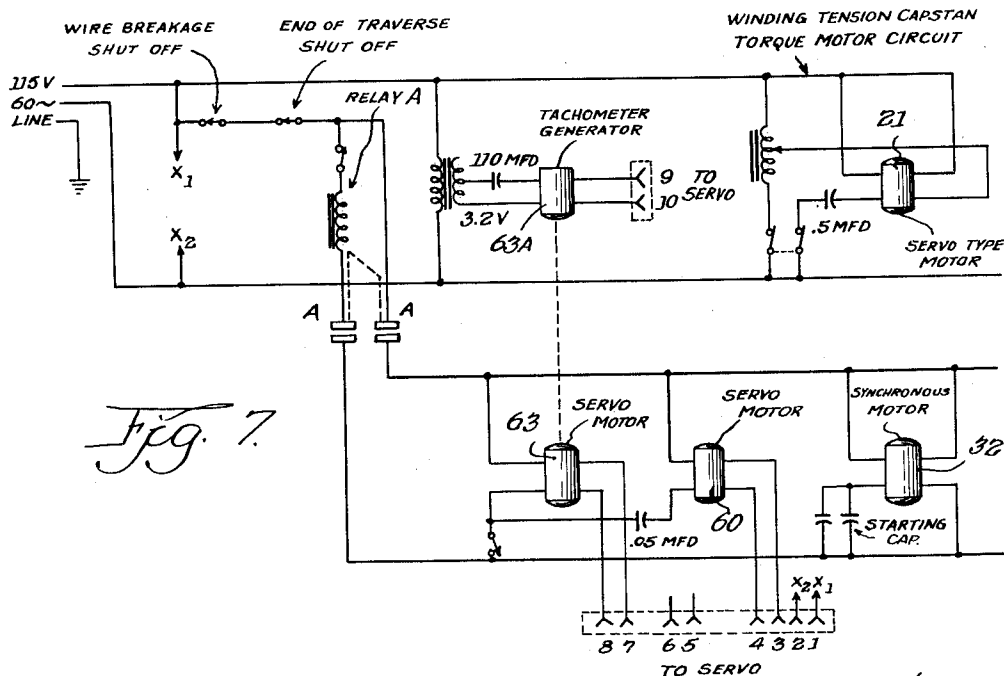
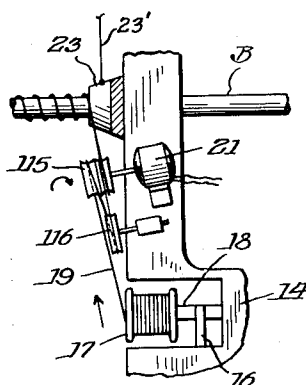


Fig. 7.

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METHOD AND APPARATUS FOR MANUFACTURING POTENTIOMETER RESISTORS

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Filed Apr. 15, 1959, Ser. No. 806,551
15 Claims. (Cl. 242—9)

This invention relates to a method and apparatus for the precision winding of electrical resistance elements. It is particularly concerned with the manufacture of electrical resistor elements employed in potentiometer assemblies.

In electrical circuit design one of the three essential circuit elements is resistance. Resistance elements are commonly used in electrical circuits simply to convey current into different paths or conversely to develop a voltage drop from a current flow. In producing these effects it is frequently desirable to employ extremely accurate rheostats and potentiometers to facilitate the control of the circuit. A rheostat is a two-terminal variable resistor in which the resistance is varied by the movement of a contact slider along a resistance-wire-wound resistor. A potentiometer is a three-terminal device in which the ratio of the output voltage, V_o , with respect to the input voltage, V_i , varies. In these apparatuses an input voltage is impressed across the resistor element and some mechanical provision, such as a slider contact, is made to connect to any point along the resistor to provide an output voltage. The three terminals are so used that one of them is common to both the input and output circuits. A rheostat differs from a potentiometer in that the actual resistance of the resistor element of the former is of great importance, whereas in a potentiometer the important feature is the ratio of the resistance between the slider contact and one of the electrical taps on the resistor element which receives the input current, and the overall resistance of the resistor element.

In winding the resistor element of the potentiometer the resistance wire is helically wound on an electrically insulated base to produce either a linear resistor where V_o/V_i is a linear algebraic function of the distance between the slider contact and one of the electrical taps of the resistor element which receives the input current, or a non-linear resistor where there is a non-linear relationship between V_o/V_i and the mechanical distance between the slider contact and the aforementioned electrical tap. In this latter instance, for example, it may be desired that the V_o/V_i be proportional to the sine of an angle represented by the distance from the slider contact to the electrical tap.

According to this invention there is provided a method and apparatus for the precision manufacture of the resistor element utilized in potentiometer assemblies. The instant invention provides a means for automatically controlling the number of turns per unit length of the winding by using the feedback from the electrical measurement of the winding as it is laid on the base element and correlating it with the winding control circuit which predetermines the winding pattern. Linear as well as non-linear windings can be precisely fashioned with extreme accuracy. For example, the departure from algebraic linearity of V_o/V_i will be less than about .015%.

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FIGURE 1 is a side elevation view of the mechanical elements of the winding apparatus with the turn control circuitry being shown schematically.

FIGURE 2 is a schematic representation of the co-operating electrical and mechanical elements employed in an illustrative embodiment of this invention employed to produce non-linear windings.

FIGURE 3 is a detailed illustration of the servo systems employed in controlling the rotation of the lead screw.

FIGURES 4-8 are schematic diagrams of the several electrical networks utilized in the illustrative embodiment.

FIGURES 9 and 10 illustrate constant tensioning arrangements for maintaining the resistance wire under tension during the winding operation.

In the manufacture of resistors for use in potentiometer assemblies a bare resistance-type of wire having a diameter of 0.5 to several mils is helically wound upon an insulated or non-conductor base in such a way that adjacent turns do not touch each other. Triple formvar-coated copper wire having a diameter of .015 to .125 inch is frequently used as the resistor base. This wire is conventional "enameled" magnet wire which is readily obtained and has a uniform diameter.

The desired number of turns for a given resistor design is controllable by a winding machine. Although there are many varieties of winding machines, the machine primarily functions to wind the resistance wire helically on a resistor base. The winding is effected by providing a relative rotational movement between the resistance wire supply and the resistor base. The axis of this relative rotation must be parallel to the resistor base. The helical form of the winding is effected by providing a relative translational movement between the resistor base and the instantaneous point-of-lay of the resistance wire. This relative motion must also be parallel to the axis of the resistor base. In the instant invention the number of turns per square inch, N , of resistance wire can be varied or maintained constant as the resistor is being wound so that the electrical characteristics of the resistor (under constant automatic measurement during winding), when finished, closely coincide with a set of predetermined values. The desired variation in the number of turns per square inch, N , is produced by changing the relation between the velocity of the aforementioned rotational movement and the velocity of the translational movement.

In the drawings there is illustrated a complete specific embodiment of the instant invention which can be adapted for the manufacture of linear or non-linear wound resistors. The mechanical arrangement comprises a frame 10 having transverse base 11 supporting uprights 12 and 13. Transverse base 11 also functions as a track for carriage 14 which travels across base 11 during the winding operation. Carriage travel is regulated by lead screw 15 which is journaled in suitable bearings (not shown) installed in uprights 12 and 13. Lead screw 15 engages with an internally threaded bore traversing carriage 14 in such a manner that the rotation of lead screw 15 affects a corresponding lateral movement of carriage 14 along base 11. A rotatable resistance wire supply bobbin 17 is mounted on spindle 18 which is braked by a conventional tension controlling means such as a shoe 16 engaging spindle 18. The pressure of the shoe is controlled

as shown in FIGURE 9 by spring loaded idler arm 16A which is pivotally mounted on the frame of carriage 14. Idler arm 16A is connected by a linkage arrangement (not shown) to shoe 16 which engages spindle 18. Shoe 16 is secured at one end to the carriage frame by a spring connection and at the other end to idler arm 16A. Additional tension control is provided by capstan 20 which is rotated by servo type motor 21 mounted on arm 22 which depends upwardly from the body of carriage 14. Capstan motor 21 is powered by a particular constant voltage for each particular degree of tension desired. The characteristics of the fractional horsepower A.C. two phase motor employed in driving the capstan are such that the torque on the capstan is essentially independent of the "backward" speed of the motor. One turn of resistance wire 19 leaving spool 17 is wrapped around capstan 20 prior to being wound on resistor base B. Motor 21 is designed to normally rotate in a direction opposite to the relative movement of the resistance wire, e.g., clockwise, at a constant voltage. With the resistance wire being pulled around capstan 20 by the rotation of resistor base B the normal rotation of motor 21 is overcome and it is driven with a backward rotation. Under these conditions there is exerted by the motor a torque sufficient to maintain the wire under a constant tension. In FIGURE 10 is schematically illustrated a double sheave arrangement which provides a more effective tensioning arrangement in cases where the friction between the capstan and the wire is too low to prevent slippage. A double groove capstan 115 cooperating with idler sheave 116 is used. By employing a double wrapping of the resistance wire around the gang capstan 115 a greater frictional force is available.

Nosepiece 23 fabricated from a wear resistant conductive material such as Carbolloy is mounted on arm 22 and insulated therefrom by insulated spacer 24. Nosepiece 23, which has an axial bore only slightly larger than the diameter of resistor base B and through which resistor base B passes, serves to make electrical contact with resistance wire 19 at the point of lay. Resistor base B is stretched tautly between a pair of rotatably mounted resistor base chucks 26 and 25 suitably journaled in uprights 12 and 13. In this embodiment a conventional slip ring arrangement is employed as an electrical connection to couple the resistance wire mounted at one end to rotating chuck 25 with the electrical control network hereinafter discussed. The slip ring consists of a continuous electrically conductive ring 27 mounted on an insulator 28 which is integrally connected to rotating shank 29 of chuck 25. Brush 30 mounted on depending bracket 31 is employed to deliver current to the continuous ring 27. Brush 30 is connected to a suitable electrical power supply included in the electrical control network.

Synchronous motor 32 installed on bracket 33 depending outwardly from upright 12 rotates drive shaft 34. To avoid slippage toothed drive belts 35 and 36 engage drive sprockets 35A and 36A mounted on drive shaft 34 and couple them to chuck sprockets 35B and 36B.

Lead screw 15 is driven by means of a pair of servo systems operated by an appropriate signal from the electrical control network. One of the servo systems is a low speed response system having a wide range of speed control. The other servo system is a high speed response velocity servo system having a narrow range of speed control. In the former system is included a variable ratio drive 41 such as a Model 30A Graham Drive having its input shaft coupled to shaft 40 which is an extension of the rotating shaft upon which chuck 26 is integrally mounted. This drive 41 consists of drive shaft 42 journaled in reciprocating yoke 43 which is moved to and fro by lead screw 44. Drive wheel 45 driven by drive shaft 42 frictionally engages the face of driven wheel 46. Drive wheel 45 in engaging driven wheel 46 at varying positions along a radius thereof changes the angular velocity or revolutions per unit time of driven wheel 46. Servo

motor 60 rotates lead screw 44 through gear box 61 in the electrical control network. The output of variable ratio drive 41 is connected to one input of differential gear 47. Although a Graham Drive is illustrated, other conventional variable ratio drives can also be used. The other input to differential gear 47 is provided by another servo motor 63 in the latter servo system of the electrical control network.

An illustrative gear train arrangement and accompanying servo motors are shown in FIGURE 3 in which driven wheel 46 is connected to spur gear 48 having one hundred teeth. Spur gear 49 which has ninety-six teeth meshes with spur gear 48. Bevel gear 50 which is rotatably mounted concentric with output shaft 51 is directly connected to spur gear 49. Bevel gear 50 in cooperation with bevel gear 52 drives intermediate bevel gear 51A which is rotatably mounted on spur shaft 51B which perpendicularly depends from output shaft 51. The rotation of output shaft 51 is effected by driving bevel gears 50 and 52 respectively at different relative speeds. Under these conditions the rotational movement of the output shaft 51 is proportional to the algebraic sum of the revolutions per unit time of bevel gears 50 and 52. Bevel gear 52 is driven by worm gear 53 and worm 54 having a 30:1 ratio. Worm 54 is rotated by servo motor 63. Spur gear 55 having twenty-six teeth is coupled to output shaft 51 and meshes with spur gear 56 having one hundred thirty teeth which is directly connected to 8 pitch lead screw 15.

Accordingly the movement of carriage 14 is controlled by the two servo systems which regulate the rotation of lead screw 15 driving carriage 14. Differential gear 47 input provided by the servo system including servo motor 60 has a wide range of speed control (a factor of about 7 between the highest and lowest speeds). The response or rate of change of speed, however, is slow, i.e., a maximum of about 1½% per second. While differential gear 47 input provided by the servo system including servo motor 63 has only a narrow range of variability (a maximum of about plus or minus 65%) it has a high speed of response with less than 0.1 second being required for the complete change from highest to lowest speed. In Table I is summarized the speed ranges at the various stations indicated in the embodiment shown in FIGURE 3.

TABLE I

Station No.	Highest Speed	Lowest Speed
A	1,800	139
B	925	144
C	960	±7.2
D ¹	±48	72
D ²	480	14.4
E	96	±432
F	±2,880	±.0135
G	±.09	±6
H	±40	

¹ Station C Stationary.
² Station F Stationary.
³ R.p.m.

The electrical control network employed for non-linear winding includes a master function generator potentiometer 70. Resistor element 71 is provided with a plurality of taps 72A-72D inclusive, which are connected to a plurality of so-called "padding potentiometers" P₇₃-P₇₇ inclusive as shown in FIGURES 1 and 2. Slider contact 78 which is related to the point of lay of the resistance wire 19 on resistor base B in an accurately proportional manner is mounted on wheeled frame 79 which is spring-coupled to arm 22 of carriage 14 and travels along a track provided by the opposed edges of master potentiometer 70. In order to compensate the travel of slider contact 78 along master potentiometer 70 for slightly varying lengths of resistor (distance between the end taps) a micrometer adjustment can be used. Because winding 71 and the track of frame 70' upon which the slider control 78 travels are not parallel with the track

on base 11 upon which carriage 14 travels, slider drive arm 80 which is pivotally mounted at point 80' on arm 22 is positioned by shaft 81 which is adjustable by means of micrometer screw 82.

From the schematic drawings of the electrical control circuits shown in FIGURES 1, 2, and 8 as further illustrated by the more specific circuitry in FIGURES 4-7, it will be seen that the feed back from the electrical measurement of the winding to the servo control systems automatically controls the number of turns of the resistance wire on resistor base B. To facilitate a presentation of the electro-mechanical network employed in the illustrative embodiment the various sections thereof are presented in separate figures all of which are correlated by the symbol system utilized to illustrate the electrical interconnections made between the circuitry shown in each of the figures.

In FIGURES 4, 5, and 7 the electrical connections between each of the illustrated circuits are made between corresponding arabic numbers or letters. For example, d_1 connection in FIG. 4 is interconnected with d_1 connection in FIG. 5. Similarly, the servo junction plate provided with numerals 1-8, illustrates schematically an electrical plug and socket arrangement wherein plug connection No. 1 in FIG. 4 is coupled to socket No. 1 shown in FIG. 7. The various electrical components employed in the illustrative control network are conventional electrical elements and where shown have the specific values set forth.

Several methods of employing the feedback as an electrical input signal can be used. In the so-called "derivative" method the electrical network schematically illustrated in FIGURE 8 compares the resistance R_d , of a fixed length of the last portion of the winding laid on the resistor base with a precision reference resistance, RES. The algebraic result of any difference in the two resistances provides a signal which is amplified by amplifiers 90 and applied to the servo motors 60 and 63 controlling the number of turns per square inch of resistance wire wound on resistor base B by causing the servo system to control the rotational speed of lead screw 15 which results in R_d of the winding being substantially equal to the value of precision resistance, RES. This method is most suitable for producing linear windings. An illustrative device for electrically measuring the resistance of the selected length of the last position of the winding laid on resistor base B is shown as an accessory on the winding device illustrated in FIGURE 1. This accessory is employed solely during the winding of linear resistance elements and is inoperative during the use of the machine as a means for winding non-linear resistances. This arrangement is used because it is advantageous to measure only the last portion of the resistance being wound and compare it with the corresponding portion of a previously wound precision resistance element used as a reference in order to minimize error. When the apparatus is being employed in winding non-linear resistances this accessory can be dismantled from carriage 14 or made inoperative by de-energizing the various electrical connections which lead to and from the accessory. This accessory comprises bracket 95 attached to carriage 14 by depending leg 96 with upright arm 97 attached thereto. Rotatable slip ring 98 has continuous electrically conductive ring 99 mounted on rotating shank 100 and insulated therefrom. Shank 100 is suitably journaled in arm 97. Electrical contact with ring 99 for delivering current thereto from a suitable power supply through electrical lead 106 is made through brush 101 which is held in brush mounting 102 held in place on the inwardly directed flanged terminal end of bracket arm 97. The slip ring assembly 98 is rotated at a substantially constant speed in the same direction and at the same speed as the rotation of resistor base B by means of a toothed belt and pulley drive 103 which couples synchronous motor 104 with a pulley mounted on shank 100. Power to synchronous motor

104 is provided as shown in FIGURE 7. Electrical contact is made with the rotating winding by means of slider 105 which is secured to ring 99 and rotates therewith.

Although the aforementioned system of turns per square inch control can be carried out for non-linear winding by programming the value of precision resistance, RES, as the winding progresses, this system is most suitable for linear windings. A preferred method for winding a non-linear resistor in accordance with this invention is the "master potentiometer" method schematically illustrated in FIGURE 2. In this method a function generator is initially set up in such a manner that, as the point of lay of the winding progresses from the beginning, the function generator will supply a voltage to control the number of turns per square inch.

An illustrative function generator is shown in FIGURES 1, 2, and 5 in which potentiometer 70 having a multi-tapped resistor is employed. The "padding potentiometers" P_{73} through P_{77} control the shape of the curve V_o/V_1 of the master function generator potentiometer 70 as slider 78 mounted in frame 79 moves along the master potentiometer winding 71.

With the "initial turns" having been wound during the pretravel at any chosen N, assume that the winding machine is stationary with the point of lay at X_o (where one resistor tap will later be attached). For a given pre-setting of the padding potentiometers P_{73} through P_{77} and potentiometer P_{106} , potentiometer P_{107} is adjusted so that the input to servo amplifier 90 is zero, i.e. nose piece voltage, V_{XN} , equals slider voltage, V_{XS} .

In operation the winding machine is started. At each point X as the winding progresses away from point X_o slider 78 will be at a voltage V_{XS} and nose piece 23 will be at a voltage V_{XN} . If these two voltages are equal, both servo motors 60 and 63 will come to rest. If the voltages are not equal, both servo motors will receive power from the amplifiers 90A and 90B in such phase as provided by phase shifter 91 as to make them rotate in the proper direction to increase N if V_{XN} is lower than V_{XS} and to decrease N if V_{XN} is the higher.

In practice the servo systems here employed consistently maintain an error signal equivalent to less than one third turn error of resistance winding, except after large discontinuities. These discontinuities are present at taps in the master potentiometer if the padding potentiometers are adjusted to have a large effect.

It is obvious that V_{XS}/V_{ref} is not proportional to V_o/V_1 of the finished desired mandrel. Accordingly, the function V_{XS}/V_{ref} is obtained in the following manner. The curve V_o/V_1 versus V is available beforehand as either a graph, or an equation, or a series of point values. The overall resistance R is also specified.

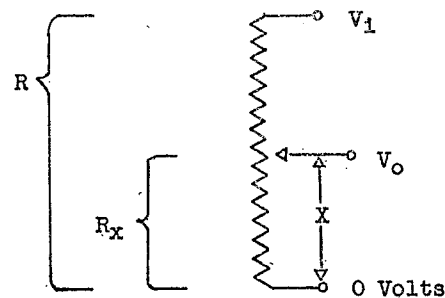


FIGURE A—PERFECT THEORETICAL FINISHED MANDREL

For each point X along the resistor in FIGURE A:

$$\begin{aligned} \text{Equation 1} \quad & V_o/V_1 = R_x/R \\ \text{Equation 2} \quad & R_x = R(V_o/V_1) \end{aligned}$$

In FIGURE B, however, which contains the identical resistor in an electrical circuit closer to that of the re-

sistor being wound in accordance with the instant invention:

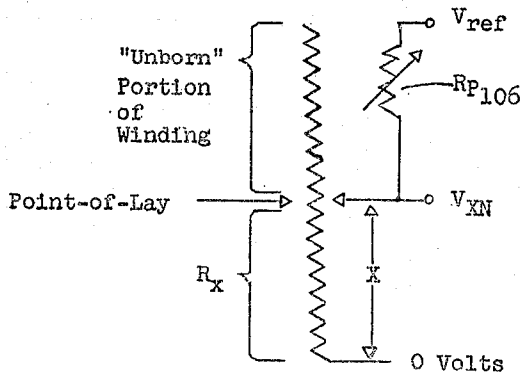


FIGURE B—RESISTOR OF FIGURE A BEING WOUND

Equation 3

$$\frac{V_{XN}}{V_{ref}} = \frac{R_x}{R_x + R_{P106}}$$

Substituting for R_x from Equation 2:

Equation 4

$$\frac{V_{XN}}{V_{ref}} = \frac{R(V_0/V_i)}{R(V_0/V_i) + R_{P106}}$$

R_{P106} is some convenient value. The larger R_{P106} is, the more constant is the error signal caused by one too many or too few turns of resistance wire as the point of lay moves from bottom to top. On the other hand, larger values of R_{P106} dissipate more of the ref voltage and thus require higher ref voltage with consequent heating of the padding potentiometers. A practical system may have $R_{P106} = R$.

Then:

Equation 5

$$\frac{V_{XN}}{V_{ref}} = R \frac{(V_0/V_i)}{(V_0/V_i + 1)}$$

The values of V_{XN}/V_{ref} can thus be computed for as many values of X as may be required from an accuracy standpoint. The further the departure of V_{XN}/V_{ref} versus X from algebraic linearity, the greater the number of points needed to produce any given accuracy.

After the values of V_{XN}/V_{ref} are known, the number and placement of the padding taps for the padding potentiometers (as illustrated by P_{73} through P_{77} of FIGURE 2) are determined.

Accuracy requirements here again control the number and placement of the taps. It is often convenient to make this determination graphically, the V_{XN}/V_{ref} values being considered as linear between any two adjacent padding taps.

After the required number of taps have been placed in the master potentiometer 70 and connected to padding potentiometers P_{73} – P_{77} , the padding potentiometers are adjusted so that at each tap along the master potentiometer 70 there exists the precise value of V_{XN}/V_{ref} required by Equation 5.

Manually pre-setting variable ratio drive 41 to produce an initial N equal to that computed to be required when starting a winding contributes greatly to the accuracy of the initial portion of the winding.

When the point of lay reaches the position of the other resistor tap, the servo amplifiers are shut off so that the over-travel is completed without servo interference.

Unservoed linear windings can also be provided by setting variable drive ratio 41 for a given r.p.m. input to differential gear 47. With servo motor 60 remaining motionless (e.g. by employing an electrical switch for shutting off the power to the motor) and servo motor 63 operating at a constant speed (including zero), the apparatus of this invention will wind a helical resistor forty inches long with such accuracy that the departure

from algebraic linearity of V_0/V_i will often be less than 0.03%. Even with the extreme mechanical accuracy provided by the machine, lack of uniformity in the resistor base and resistance will produce uncontrolled departures from the predetermined linearity.

In FIGURE 6 is schematically illustrated a servo system showing speed limiting systems for limiting the maximum r.p.m. of servo motor 63. This is necessary because of the extreme range of possible N provided by the variable ratio drive settings. If too rapid speed of servo motor 63 is possible, then a momentary large error signal (caused inadvertently, for example, by momentary loss of contact of the slider) could cause a "shorted" turn which would destroy the accuracy of the winding. The limiting is accomplished with the servo amplifier 90 connected together with servo motor 63 and the tachometer generator 63A as an ordinary velocity servo. Because of the negative feedback from the tachometer generator 63A and the large amplification of the A.C. amplifier 90 for each value of voltage output of voltage limiter 111 servo motor 63 will maintain a corresponding speed, essentially independent of its mechanical load.

The servo pre-amplifier 110 is constructed in such a way that its maximum output voltage is internally limited. Output voltage limiter 111 is a conventional arrangement illustrated, for example, by a pair of non-linear resistors in parallel (rectifiers such as IN482A) across the output with plus connected to minus. Accordingly, whatever the error voltage ($V_{XN} - V_{XS}$) may be, the pre-amplifier output may not go above the limiting value. Mixer 112 is so constructed (in the illustration is shown a transformer mixer 110, although there are many other kinds) that with maximum attenuation of the tachometer generator attenuator 113, tachometer generator 63A output at the maximum speed of servo motor 63 will equal the limiting pre-amplifier output voltage. At the minimum attenuation setting the servo motor 63 speed will be limited to 10% of its maximum. As the attenuation is increased, the servo motor maximum speed becomes greater. Finally, when the attenuator only allows 10% of the tachometer generator output to reach mixer 112 the imposed servo motor speed limit reaches its natural speed limit.

It is apparent from the foregoing detailed discussion that the features of this invention can be modified by those skilled in this art without departing from the scope of the invention. Although several specific embodiments were discussed, they are considered as illustrative and non-limiting. Accordingly, the instant invention is limited only in the manner set forth in the appended claims.

What is claimed is:

1. A method for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on a non-conductive resistor base which comprises rotating a tautly held resistor base about its longitudinal axis at a substantially constant speed by a motor driven means, helically winding a length of resistance wire applied under constant tension around said resistor base, maintaining a relative translational movement between the resistor base and an instantaneous point-of-lay of said resistance wire on said base along an axis parallel to the longitudinal axis of said base, continuously impressing an electrical potential across at least a portion of the resistance wire wound on said base including the wire at said point of lay to produce a first electrical voltage signal, continuously applying an electrical potential across at least one reference resistance element to produce a second electrical voltage signal, algebraically combining said first and second signals to provide an error voltage, applying said error voltage simultaneously to a high-speed response velocity servo system having a narrow range of speed control and a low-speed response servo system cooperating with said motor-driven means and having a wide range of speed control to convert said error voltage to mechanical out-

put, correlating the mechanical output from said servo systems to produce a differential mechanical output, and employing said differential output to control said translational movement.

2. A method for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on a non-conductive resistor base which comprises rotating a tautly held resistor base about its longitudinal axis at a substantially constant speed by a motor driven means, helically winding a length of resistance wire applied under constant tension around said resistor base, maintaining a relative translational movement between the resistor base and an instantaneous point-of-lay of said resistance wire on said base along an axis parallel to the longitudinal axis of said base, continuously impressing an electrical potential across at least a portion of the resistance wire wound on said base including the wire at said point of lay to produce a first electrical voltage signal, continuously applying an electrical potential across at least one reference resistance element to produce a second electrical voltage signal, algebraically combining said first and second signals to provide an error voltage, amplifying said error voltage and applying the amplified voltage simultaneously to a high-speed response velocity servo system having a narrow range of speed control and a low-speed response servo system cooperating with said motor driven means and having a wide range of speed control to convert said error voltage to mechanical output, correlating the mechanical output from said servo systems to produce a differential mechanical output, and employing said differential output to control said translational movement.

3. A method for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on a non-conductive resistor base which comprises rotating a tautly held resistor base about its longitudinal axis at a substantially constant speed by a motor driven means, helically winding a length of resistance wire applied under constant tension around said resistor base, maintaining a relative translational movement between the resistor base and an instantaneous point-of-lay of said resistance wire on said base along an axis parallel to the longitudinal axis of said base, by a means transported by a lead screw continuously impressing an electrical potential across at least a portion of the resistance wire wound on said base including the wire at said point of lay to produce a first electrical voltage signal, continuously applying an electrical potential across at least one reference resistance element to produce a second electrical voltage signal, algebraically combining said first and second signals to provide an error voltage, amplifying said error voltage and applying the amplified voltage simultaneously to a high-speed response velocity servo system having a narrow range of speed control and a low-speed response servo system cooperating with said motor driven means and having a wide range of speed control to convert said error voltage to mechanical output, correlating the mechanical output from said servo systems to produce a differential mechanical output, and employing said differential output to drive said lead screw and to control said translational movement.

4. A method for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on a non-conductive resistor base to produce a linear resistor which comprises rotating a tautly held resistor base about its longitudinal axis at a substantially constant speed by a motor driven means, helically winding a length of resistance wire applied under constant tension around said resistor base, maintaining a relative translational movement between the resistor base and an instantaneous point-of-lay of said resistance wire on said base along an axis parallel to the longitudinal axis of said base, continuously impressing an electrical

potential across a portion of the resistance wire wound on said base including the wire at said point of lay to produce a first electrical voltage signal, continuously applying an electrical potential across a reference resistance element to produce a second electrical voltage signal, algebraically combining said first and second signals to provide an error voltage, amplifying said error voltage and applying the amplified voltage simultaneously to a high-speed response velocity servo system having a narrow range of speed control and a low-speed response servo system cooperating with said motor driven means and having a wide range of speed control to convert said error voltage to mechanical output, correlating the mechanical output from said servo systems to produce a differential mechanical output, and employing said differential output to control said translational movement.

5. A method for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on a non-conductive resistor base to produce a non-linear resistor which comprises rotating a tautly held resistor base about its longitudinal axis at a substantially constant speed by a motor driven means, helically winding a length of resistance wire applied under constant tension around said resistor base, maintaining a relative translational movement between the resistor base and an instantaneous point-of-lay of said resistance wire on said base along an axis parallel to the longitudinal axis of said base, continuously impressing an electrical potential across the resistance wire wound on said base from the initial turn to the point of lay of said wire to produce a first electrical voltage signal, sequentially applying an electrical potential across a plurality of reference resistance elements having a predetermined program of resistance in accordance with the non-linear characteristics of said non-linear resistor to produce a second electrical voltage signal, algebraically combining said first and second signals to provide an error voltage, amplifying said error voltage and applying the amplified voltage simultaneously to a high speed response velocity servo system having a narrow range of speed control and a low speed response servo system cooperating with said motor driven means having a wide range of speed control to convert said error voltage to mechanical output, correlating the mechanical output from said servo systems to produce a differential mechanical output, and employing said differential output to control said translational movement.

6. An apparatus for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on an insulated resistor base which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin, a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base, and an electrically conductive nose piece having an axial bore, said nose piece being electrically insulated from said carriage; controllable means for varying the transverse movement of said carriage; a pair of opposed, rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore, said chucks being coupled to a motor driven means for simultaneously driving said chucks at a substantially constant speed; an electrical connection means for delivering current to a resistance wire coupled to one of said chucks; an electrical control network comprising a reference resistance means adapted to supply an electrical voltage signal, first means for supplying power to said reference resistance means, a second means for supplying power across said electrical connection means and said nose piece to provide an electrical voltage signal, said reference resistance means and said nose piece being electrically connected to an amplifier means for algebraically com-

binning said electrical signals and providing an amplified output voltage, a high speed response velocity servo system having a narrow range of speed control, and a low speed response servo system, said low speed response servo system cooperating with said motor driven means and having a wide range of speed control, said servo systems respectively including servo motors electrically connected in parallel to the electrical output of said amplifier means, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to said control means for varying the transverse movement of said carriage.

7. An apparatus for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on an insulated resistor base which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base, and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement, a pair of opposed, rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore; said chucks being coupled to a motor driven means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks; an electrical control network comprising a reference resistance means adapted to program the winding of the resistance wire and to supply an electrical voltage signal, a first means for supplying power to said reference resistance means, a second means for supplying electrical power across said electrical connection means and said nose piece to provide an electrical voltage signal, said reference resistance means and said nose piece being electrically connected to an amplifier means for algebraically combining said electrical signals to provide an amplified electrical voltage signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

8. An apparatus for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on an insulated resistor base which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base, and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement, a pair of opposed, rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore; said chucks being coupled to a motor driven means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks, an electrical control network comprising a

reference resistance means adapted to program the winding of the resistance wire and to supply an electrical voltage signal, a first means for supplying power to said reference resistance means, a second means for supplying electrical power across said electrical connection means and said nose piece to provide an electrical voltage signal, said reference resistance means and said nose piece being electrically connected to an amplifier means for algebraically combining said electrical signals to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a variable ratio drive having a first substantially constant speed input provided by said motor-driven means and a second input provided by said servo motor, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

9. An apparatus for controlling the number of turns of resistance wire helically wound side by side in a spaced relationship on an insulated resistor base to provide a linear wound resistor which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base, and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement; a pair of opposed, rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore; said chucks being coupled to a motor-driven means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks mounted on said carriage adjacent said nose piece; an electrical control network comprising a bridge circuit, a reference resistance element adapted to program the linear winding included in one of the parallel legs of said circuit, and said electrical connection and said nose piece being connected in the other parallel leg of said circuit, and means for supplying electrical power to said circuit, the output from said circuit being electrically connected to an amplifier means to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

10. An apparatus for controlling the number of turns of resistance wire helically wound side by side in a spaced relationship on an insulated resistor base to provide a linear wound resistor which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant

tension on said resistance wire as it is laid on said resistor base, and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement; a pair of opposed, rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore; said chucks being coupled to a motor-driven means for simultaneously driving said chucks at a substantially constant speed, a rotatable electrical connection means mounted on said carriage adjacent said nose piece for delivering current to a resistance wire coupled to one of said chucks, said connection adapted to rotate at the same speed and in the same direction as said chucks; an electrical control network comprising a bridge circuit, a reference resistance element adapted to program the linear winding included in one of the parallel legs of said circuit, and means for supplying electrical power to said circuit, the output from said circuit being electrically connected to an amplifier means to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

11. An apparatus for controlling the number of turns of resistance wire helically wound side by side in a spaced relationship on an insulated resistor base to provide a linear wound resistor which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base, and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement; a pair of opposed, rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore; said chucks being coupled to a motor-driven means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks mounted on said carriage adjacent said nose piece; an electrical control network comprising a bridge circuit, a reference resistance element adapted to program the linear winding included in one of the parallel legs of said circuit, and said electrical connection and said nose piece being connected in the other parallel leg of said circuit, and means for supplying electrical power to said circuit, the output from said circuit being electrically connected to an amplifier means to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a variable ratio drive having a first substantially constant speed input provided by said motor-driven means and a second input provided by said servo motor, and a mechanical differentiating means coupled to the outputs of

said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

12. An apparatus for controlling the number of turns of resistance wire helically wound side by side in a spaced relationship on an insulated resistor base to provide a linear wound resistor which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base, a servo type motor mounted on said carriage having a driven sheave adapted to rotate in a relative direction opposite to the travel of resistance wire past said sheave, and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement; a pair of opposed, rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore; said chucks being coupled to a motor-driven means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks mounted on said carriage adjacent said nose piece; an electrical control network comprising a bridge circuit, a reference resistance element adapted to program the linear winding included in one of the parallel legs of said circuit, and said electrical connection and said nose piece being connected in the other parallel leg of said circuit, and means for supplying electrical power to said circuit, the output from said circuit being electrically connected to an amplifier means to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

13. An apparatus for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on an insulated resistor base to provide a non-linear wound resistor which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement, a pair of opposed rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore, said chucks being coupled to a motor means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks; an electrical control network comprising a function generator including a master potentiometer adjustable to provide a non-linear winding program by means of a plurality of padding potentiometers electrically connected to said master potentiometer and having a slider contact actuated by said carriage, said slider being adapted to provide an output voltage signal, a first means for supplying an input voltage to said potentiometer, a second means for supplying power across said electrical connection means and said nose piece to provide

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an electrical voltage signal, said slider contact and said nose piece being electrically connected to an amplifier means for algebraically combining said electrical signals to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

14. An apparatus for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on an insulated resistor base to provide a non-linear wound resistor which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement, a pair of opposed rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore, said chucks being coupled to a motor means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks; an electrical control network comprising a function generator including a master potentiometer adjustable to provide a non-linear winding program by means of a plurality of padding potentiometers electrically connected to said master potentiometer and having a slider contact actuated by said carriage, said slider being adapted to provide an output voltage signal, a first means for supplying an input voltage to said potentiometer, a second means for supplying power across said electrical connection means and said nose piece to provide an electrical voltage signal, said slider contact and said nose piece being electrically connected to an amplifier means for algebraically combining said electrical signals to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a variable ratio drive having a first substantially constant speed input provided by said motor-driven means and a second input provided by said

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servo motor, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

15. An apparatus for controlling the number of turns of resistance wire helically wound side by side in spaced relationship on an insulated resistor base to provide a non-linear wound resistor which comprises a base having a pair of opposed uprights depending therefrom; a carriage mounted on said base and adapted to move to and fro between said uprights, said carriage being provided with a rotatable resistance wire supply bobbin; a tension controlling means for maintaining a constant tension on said resistance wire as it is laid on said resistor base, a servo type motor mounted on said carriage having a driven sheave adapted to rotate in a relative direction opposite to the travel of resistance wire past said sheave, and an electrically conductive nose piece having an axial bore, said nose piece being insulated from said carriage; a controllable lead screw threadably engaging said carriage to effect its movement, a pair of opposed rotatable resistor-base chucks journaled respectively in said uprights, the axis of rotation of said chucks being aligned with said axial bore, said chucks being coupled to a motor means for simultaneously driving said chucks at a substantially constant speed, an electrical connection means for delivering current to a resistance wire coupled to one of said chucks; an electrical control network comprising a function generator including a master potentiometer adjustable to provide a non-linear winding program by means of a plurality of padding potentiometers electrically connected to said master potentiometer and having a slider contact actuated by said carriage, said slider being adapted to provide an output voltage signal, a first means for supplying an input voltage to said potentiometer, a second means for supplying power across said electrical connection means and said nose piece to provide an electrical voltage signal, said slider contact and said nose piece being electrically connected to an amplifier means for algebraically combining said electrical signals to provide an amplified electrical signal, a high speed response velocity servo system having a narrow range of speed control, said high speed response velocity servo system including a servo motor operated by said amplified signal, a low speed response servo system cooperating with said motor-driven means and having a wide range of speed control, said low speed response servo system including a servo motor operated by the output of said amplifier means, and a mechanical differentiating means coupled to the outputs of said servo systems, the output from said differentiating means being coupled to and driving said lead screw.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,989,256

June 20, 1961

Arnold S. J. Lee

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 20, after "curve" insert -- of --; line 49, for "fuction" read -- function --; same column 6, line 50, for "versus V" read -- versus X --; column 7, line 28, for "B_{P106}" read -- R_{P106} --; column 9, line 32, strike out "mechanical output, and employing said differential"; line 50, for "refrence" read -- reference --.

Signed and sealed this 21st day of November 1961.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

DAVID L. LADD

Commissioner of Patents

USCOMM-DC

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