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METHOD OF AND APPARATUS FOR WINDING PRECISION RESISTORS

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FIG. 1

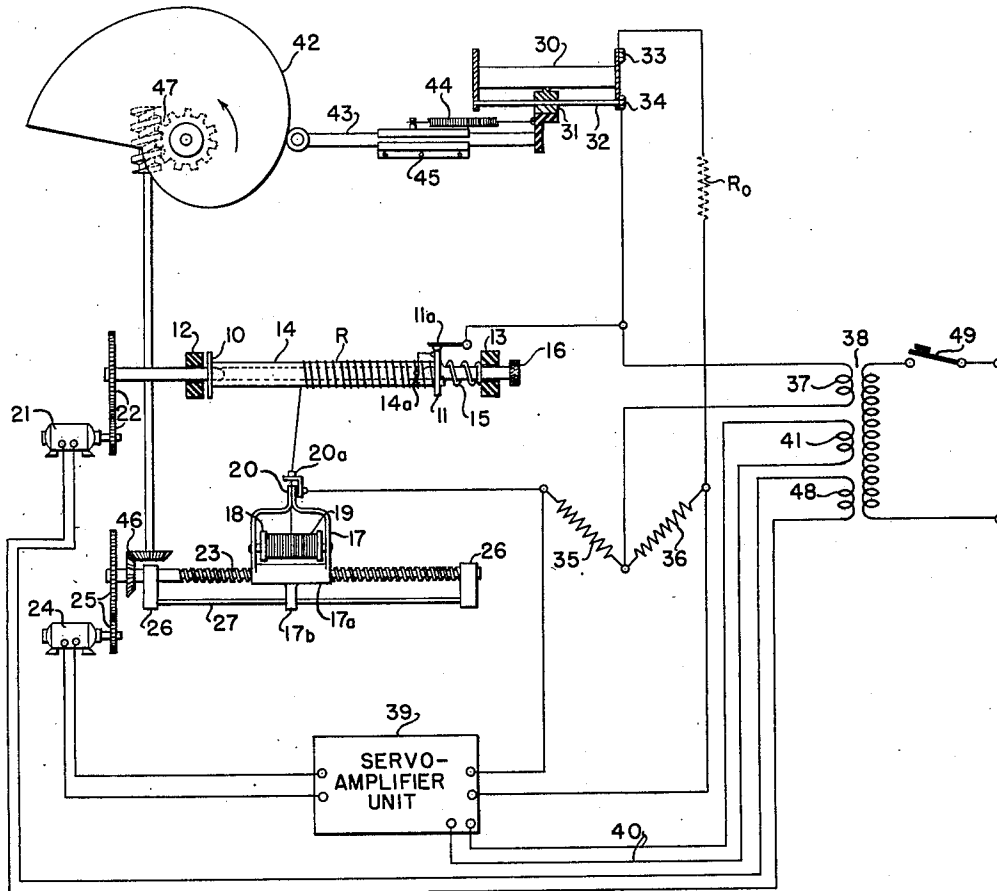


FIG. 2

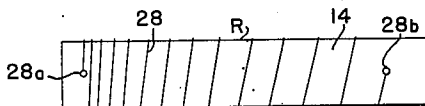
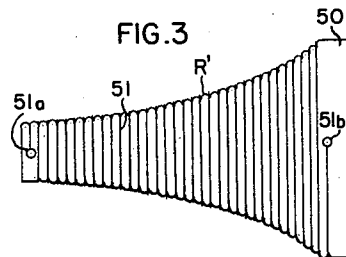


FIG. 3



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METHOD OF AND APPARATUS FOR WINDING
PRECISION RESISTORSHenry Erwin Hale, Freeport, N. Y., assignor to
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24 Claims. (Cl. 242—9)

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This invention relates to a method of, and apparatus for, winding precision resistors and is particularly applicable to the manufacture of adjustable resistors, such as voltage dividers and potentiometers of the type having an accurately predetermined resistance characteristic over their range of resistance adjustment.

Heretofore, adjustable resistors have been formed on elongated cards or forms of rectangular or cylindrical shape if a linear characteristic is desired. If a nonlinear characteristic is desired, the resistors have been formed on a rectangular card and made up of short sections of different but uniform resistance characteristics or wound continuously on a properly tapered form.

In all of the arrangements described, the accuracy of the resistance characteristic depends upon the uniformity of the wire and the form on which the resistance wire is wound. It has been difficult to fabricate resistors of precisely predetermined characteristics due to lack of uniformity of the wire, such as uniformity in its cross section and in its tempering, and the difficulty of maintaining a constant tension during the winding process. Utilizing the best obtainable wire and winding techniques developed, the highest degree of accuracy has included deviations of $\pm 2\%$ from the desired resistance characteristic, even using carefully selected resistance wire. The usual commercial tolerance has been within the range of $\pm 10\%$ from the desired resistance characteristic. Furthermore, in the use of sectionalized resistors to procure a non-uniform characteristic, the resultant characteristic is stepped rather than continuous, resulting from the series of uniform sections having different unit resistances. In the latter type of resistor, as the winding advances from section to section, it has required the stopping of the winding machine and the changing of gears, which is inherently a tedious process. Furthermore, in the sectionalized type of resistor, it has been the practice to form the junction by slotting the resistor card and to overlap the windings in the slot to form a mechanical joint. It has also been proposed to pre-join several lengths of wire of different sizes and unit resistance. However, in either type of constructions such junctions must be accurately predetermined and the winding machine stopped and the gears changed at each junction.

It is an object of the present invention, therefore, to provide an improved method for winding precision resistors having an accurately pre-

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determined resistance characteristic which avoids one or more of the disadvantages of the arrangements of the prior art.

It is another object of the invention to provide an improved apparatus for winding precision resistors having an accurately predetermined resistance characteristic which avoids one or more of the disadvantages of the arrangements of the prior art.

In accordance with the invention, a method of winding precision resistors having a resistance characteristic accurately related to that of a reference standard comprises winding resistance wire on a card to form a resistor, continuously comparing the resistance value of the resistor during winding with that of a corresponding variable portion of the standard, continuously modifying the unit dimensions, for example, the winding pitch of the resistor, in response to deviations in the resistance value thereof from that of the portion of the reference standard with which it is compared, and introducing a nonlinear factor into the comparison to impart a predetermined resistance-displacement characteristic to the resistor.

In accordance with another feature of the invention, an apparatus for winding a precision resistor having a resistance characteristic accurately related to that of a reference standard comprises means for winding resistance wire on a card to form a resistor, means for continuously comparing the resistance value of the resistor during winding with that of a corresponding variable portion of the standard, means responsive to deviations in the resistance value of the resistor from that of the portion of said reference standard with which it is being compared for continuously controlling the action of the winding means to modify a unit dimension of the resistor, and cam means for modifying the action of the comparing means to impart a predetermined resistance-displacement characteristic to the resistor.

As used herein and in the appended claims, the term "card" is intended to mean a form or support for resistance wire of any suitable insulating material and of any desired configuration. The term "unit dimension" as used herein and in the appended claims is intended to include the pitch per turn of the resistor, or the diameter or length of the turn, the cross-sectional area of the wire, the resistance value of the wire per unit length, or any parameter which determines the resistance value per unit length of the resistor.

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For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

Referring now to the drawing, Fig. 1 is a schematic representation of an apparatus for winding a precision adjustable resistor which is capable of operating in accordance with the method of the invention; Fig. 2 is a view of a precision resistor of a predetermined length embodying the invention; Fig. 3 is a view of an alternate form of precision resistor embodying the invention.

Referring now to Fig. 1 of the drawing, there is represented an apparatus operating in accordance with the method of the invention for winding a precision resistor having a resistance characteristic accurately predetermined by that of a reference standard, for example, identical thereto. This apparatus comprises a winding mechanism consisting of a pair of holders 10 and 11 supported in bearings 12 and 13, respectively, adapted resiliently to hold an elongated resistor card 14 of insulation material, the holder 11 being biased into engagement with the card 14 by means of a spring 15. A manually operable knob 16 is provided for initiating a few turns on the card 14. The winding mechanism also includes a means for winding resistance wire on the card 14 to form a resistor R and consisting of a feed-wire holder 17 in which is mounted a spool 18 carrying a supply of resistance wire 19, the wire being passed through a guide and tensioning element 20 constituting an extension of the holder 17. The wire after passing through the element 20 is fed to the resistor card 14 in a conventional manner to form a resistor thereon. The card 14 is adapted to be rotated at constant speed by means of a suitable motor 21 and reduction gearing 22. Electrical connections are made to the resistor R during winding by means of a sliding contact 20a attached to guide 20 and bearing on the wire 19 as it is fed to card 14 and a brush 11a bearing on the conductive holder 11 which is connected to a terminal 14a on card 14 or other suitable connection to the starting point of the winding forming the final resistor R.

The winding apparatus also includes an advancing means for producing relative transverse movement between the resistor card 14 and the feed-wire holder 17 during rotation of the card 14 to form a resistor thereon. This advancing means comprises a feed screw 23 engaging a threaded portion 17a of the holder 17 and driven by a followup motor 24 through reduction gearing 25. The feed screw 23 is journaled in supports 26, 26 which also hold a guide rod 27 engaging an extension 17b of the holder 17 to maintain steady transverse movement of the holder 17.

In order to impart to the resistor formed as described a resistance characteristic accurately predetermined by that of the reference standard, the apparatus includes means for continuously comparing the resistance value of the resistor during the winding operation with that of a corresponding variable portion of a reference standard resistor. In the system illustrated, the reference standard resistor 30 is provided with an adjustable contact 31 mounted on a conductive guide 32 and provided with terminals 33 and 34 including in their circuit the adjustable portion of the resistor 30 to the right of the contact 31, as represented in the drawing. The por-

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tion of the resistor wound on the card 14 at any moment is compared with the portion of the reference resistor 30 described by means of an electrical bridge including as two adjacent arms the corresponding portions of the reference resistor 30 and the resistor R and as the other two arms resistor elements 35 and 36 of predetermined relative resistance values, the bridge being connected to compare these two resistors by electrically balancing them against each other in the bridge circuit. To this end, one secondary winding 37 of a supply transformer 38 is connected across one diagonal of the bridge circuit described, while the other diagonal of the bridge circuit is connected to the input circuit of a servo-amplifier unit 39. The unit 39 may be of any conventional type of servo-amplifier but applicant has found particularly useful for this purpose the proportional servo-amplifier described in United States Patent No. 2,147,674, Howard A. Satterlee. The power supply circuit 40 of the amplifier unit is energized from a second winding 41 of the supply transformer 38, while the output circuit of the amplifier 39 is connected to energize the follow-up motor 24 which produces a relative transverse movement between the wire-feed apparatus and the resistor card 41.

In order to sweep the adjustable contact 31 of the reference standard resistor 30 over its range of adjustment for continuously varying the resistance value of the standard during the winding operation, there is provided a cam means driven by the winding mechanism comprising a cam 42 and a follower 43 biased into engagement with the cam by means of a spring 44, the follower 43 being connected to actuate the contact 31 and operating in a guide 45. The cam 42 is driven by the follow-up motor 24 through a bevel gearing 46 and a worm gearing 47, the gear ratios being such that the cam 42 makes substantially one complete revolution while the wire holder 17 completes its transverse movement.

The motor 21 is energized from a secondary winding 48 of transformer 38, while a switch 49 included in the primary circuit is effective simultaneously to energize and de-energize the several circuits of the apparatus to start and stop the winding operation.

Referring now to the operation of the apparatus of Fig. 1 described above in performing the method of the invention for winding precision resistors, it will be assumed that the resistor card 14 is placed in the holder and a few turns wound thereon by means of the manually actuated knob 16 until the wire reaches the terminal 14a or other equivalent connection to the starting point of the winding. It is assumed that, at this point, the adjustable contact 31 is at the extreme right-hand limit of its movement, in which position all of the resistor 30 is cut out of the bridge circuit. Assuming that at this point there is a small amount of resistance, which may be inherent circuit resistance with or without an added resistance element and is represented by dotted-line resistor R₀, in circuit with the reference resistor 30 partially to compensate for the resistance of the wire between the contact 20a of the feed-wire holder 17 and the card 14, the value of resistance in the bridge arm including resistor R slightly exceeds that in the bridge arm including master resistor 30, and the bridge circuit comprising elements R, R₀, 35, 36 is slightly unbalanced. The un-

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balance voltage is applied to the amplifier 39, is amplified therein, and applied to the follow-up motor 24, initiating transverse movement of the feed-wire holder 17 to start the formation of the resistor R on the card 14. At the same time the follow-up motor 24, through the gearing 25, 46, 47 rotates the cam 42 in a counter-clockwise direction, the spring 44 biasing the follower 43 into engagement with the cam 42, which is effective to move the adjustable contact 31 of resistor 30 to the left to include continuously increasing portions of the resistor 30 in the bridge circuit.

When the apparatus described has reached a state of equilibrium, there will be a substantially constant difference in resistance between the portion of the reference resistor 30 included in the bridge circuit and the portion of the resistor wound on card 14, this difference being only the small amount required to maintain the unbalance of the bridge circuit sufficient to actuate the follow-up motor 24 for advancing the feed-wire holder 17 relative to the resistor card 14. That is, the bridge circuit, servo-amplifier unit 39, and controlled follow-up motor 24 comprise means responsive to deviations in the resistance value of the resistor R and the corresponding adjustable portion of the reference resistor 30 or any electrical unbalance therebetween for continuously controlling the relative transverse movement between the feed-wire holder 17 and the card 14 continuously to modify the unit dimensions of the resistor R, specifically, continuously varying the transverse speed of the feed-wire holder 17 to modify the pitch of the resistor, from end to end during the winding operation.

The resistance characteristic of the resistor R is accurately predetermined by that of the reference standard 30. If the throw of the cam 42 changes at a uniform rate with respect to angular displacement and the resistors 35 and 36 are of equal values, the resistance characteristic of the resistor R will be identical to that of the reference standard 30. However, in practice, it will generally be more feasible to adopt a reference standard having a characteristic which need only approximate that desired and then to shape the cam 42 according to the measured calibration curve of the reference standard. Furthermore, by selecting resistors 35, 36 with values in a predetermined ratio, the value of resistor R will bear this same ratio to that of the reference standard 30. If the resistance characteristic of the standard 30 is nonlinear, the speed of transverse movement of the feed-wire holder 17 and the winding pitch of resistor R varies continuously as the resistor is wound from end to end, thereby securing a substantial matching of the two resistor characteristics.

By the use of the resistor winding apparatus of Fig. 1 operating in accordance with the method of the invention, a number of advantages are obtained. In the first place, the resulting precision resistor can be formed of ordinary resistance wire, thereby avoiding the requirement of specially selected wire with minimum tolerances for cross-sectional area and specific resistance.

By continuously comparing the resistance of the unit being wound with the reference standard by continuously electrically balancing it in the bridge circuit from the starting point, any errors in the system tend to be self-compensating rather than cumulative. It is found that the accuracy of the resulting characteristic of the resistor is substantially independent of variations of the

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wire characteristics, the tension on the feed wire, the dimensional errors of the resistor card, and the like, but is determined almost entirely by the accuracy of the winding apparatus and its control mechanism, the only practical limit on which is the economic factor. If the variations in the resistance or in the resistance wire are beyond the limits of accuracy of the machine, it has been found that the apparatus stops winding, which is automatically an indication of a defective resistor. This is also true in the event of a failure of the Wheatstone bridge comparison circuit or the servo-amplifier 39, in which case the motor 24 is deenergized, arresting the lead screw 23 and wire holder 17 so that the wire would pile up at one spot on card 14, clearly indicating that the winding apparatus is not functioning properly.

Furthermore, in the production of resistors of nonlinear characteristic, by the use of the present invention, any desired resistance characteristic can be obtained exactly rather than merely approximated by means of a series of uniform sections of different unit resistances, which results in a stepped resistance characteristic. As a corollary, the shut-down of the winding mechanism and the change of its set-up for each of the several sections of the prior art precision resistors of nonlinear characteristics is avoided. In using the apparatus and method of the invention, it is also possible to prejoin lengths of wire of different sizes or different unit resistance or both, the lengths of the individual sections of which need not be precisely determined so long as they fall within certain wide limits.

The resistor R formed by the apparatus of Fig. 1 has a predetermined constant length and continuously varying unit dimensions from end to end, that is, continuously varying pitch which is proportioned to provide the predetermined resistance characteristic. As explained above, the variation in pitch of the resistor R is determined by a number of factors: the resistance-displacement characteristic of the reference resistor 30; the shape of the cam 42, and the relative values of resistors 35 and 36. Such a resistor R is represented in Fig. 2 where the winding of resistance wire 28 on the elongated insulation card 14 is of progressively increasing pitch from the terminal 28a to the terminal 28b.

There is illustrated in Fig. 3 a resistor R' in which the elongated card 50 is tapered to obtain approximately the desired resistance characteristic but is made of resilient material, such as semi-vulcanized rubber or thermo-plastic resin. In the winding of the resistor R', the tension of the wire is continuously controlled during the winding operation in accordance with the unbalance between the resistance of the reference standard and that of the resistor being wound so that the winding 51 is embedded to a greater or lesser degree to procure the exact proportioning of the effective diameter from end to end to obtain the desired resistance characteristic and there results a certain bulging of the elastic card 50, as indicated.

In an alternative method of winding precision tapered resistors, the speed of advance of the wire along the card may be maintained constant and the speed of rotation of the card varied in accordance with the unbalance of the resistance of the reference standard and that of the resistor being wound. The resulting resistors have a constant number of turns but lengths varying with variations in the constants of the resistance

wire and the card, as contrasted to the resistors formed by the system of Fig. 1 which are of constant length but have numbers of turns variable in accordance with the variations in the constants of the resistance wire and the card.

Thus, in the embodiments specifically described, the unit dimensions which are continuously modified during winding are the pitch of the winding, Fig. 1, and the diameter of the card or length of turn, Fig. 3. However, it will be apparent that other parameters which determine the resistance value per unit length of resistor, may be continuously modified during the winding operation to obtain the desired characteristic; for example, the cross-sectional area of the wire may be varied by grinding or abrading or the resistance per unit length may be varied by utilizing a composite wire formed of two elements of different unit resistance and varying their relative effectiveness as by depositing or abrading one of the component elements.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. Apparatus for winding a precision resistor having a resistance characteristic accurately predetermined by that of a reference standard comprising, means for winding resistance wire on a card to form a resistor, cam means driven by said winding means and an adjustable contact actuated thereby for continuously varying the resistance value of said standard, an electrical bridge including said resistor and said standard, and means responsive to an unbalance of said bridge for continuously controlling the action of said winding means to modify a unit dimension of said resistor.
2. In a potentiometer winder of the type having a master potentiometer and resistance comparison means for adjusting rate of axial traverse to rotational speed of a potentiometer being wound, means for varying the resistance of the master potentiometer in response to traverse of wire along the potentiometer being wound, and a replaceable cam interposed in said master potentiometer varying means, said cam having a contour for introducing a predetermined functional relationship in resistance variation of the master potentiometer as the potentiometer is being wound.
3. In a potentiometer winder, lead screw means for traversing wire to be wound axially along a winding form, a master potentiometer with a driving connection between the lead screw means and the master potentiometer, and a cam and cam follower linkage interposed in said driving connection, said master potentiometer having a linear relationship between its resistance and the driving motion imparted thereto and said cam having a contour such as to introduce a predetermined functional relationship in the resistance variation.
4. A potentiometer winder comprising in combination, a rotatable winding form support adapted to carry a winding form on which resistance wire is to be wound, movable lead screw means for feeding resistance wire to the wind-

ing form as it is being rotated, means for driving both the rotatable winding form support and the lead screw means with an adjustable speed ratio, a master potentiometer with resistance varying means driven by the lead screw means, a resistance comparator responsive to the relationship between the resistance of wire wound upon the winding form and the master potentiometer resistance for varying said speed ratio adjustment to vary the pitch with which wire is wound on the winding form for correcting deviations between the resistance function of the wound wire and that determined by the master potentiometer, and a linkage having a desired functional relationship interposed between said lead screw means and said master potentiometer for causing a predetermined functional variation between resistance of said master potentiometer and movement of said lead screw means in order to introduce such functional relationship into the resistance function of wire wound on said winding form.

5. A potentiometer winder comprising, in combination, a rotatable winding form support adapted to carry a winding form on which resistance wire is to be wound, movable lead screw means for feeding resistance wire to the winding form as it is being rotated, a master potentiometer means for driving the rotatable winding support and the lead screw means with an adjustable speed ratio, and means connected to be automatically responsive to said master potentiometer means for varying the speed ratio adjustment to produce potentiometers with a predetermined resistance function.

6. Apparatus as in claim 5, in which resistance measuring means is connected with said master potentiometer and with said winding form resistance wire.

7. In a potentiometer winder having means for rotating a winding form, means for traversing the wire along the winding form and means for adjusting the ratio of rotational speed to axial traverse, a master potentiometer, means for measuring the resistance of the wire being wound to form the potentiometer, and means responsive to the relative resistances of said master potentiometer and that of the wire wound for controlling the ratio adjusting means.

8. In apparatus for winding wire to form a potentiometer, means for continuously making electrical connection to a portion of wire which has already been wound into the potentiometer, a master potentiometer, and means for continuously comparing the resistances of said master potentiometer and that of the portion of wire already wound.

9. A forming machine comprising, in combination, a rotatable support adapted to carry a device being formed, movable lead screw means for feeding material to the support as it is being rotated, means for driving the rotatable support and the screw means with an adjustable speed ratio, a master variable element driven with said screw means for varying a characteristic of the master element, and a comparator responsive to the relationship between magnitudes of the predetermined characteristics of the master element and the device being formed for varying said speed ratio adjustment to vary the form of the device being formed for correcting deviations between magnitudes of the characteristics of the device being formed and the master element.

10. A potentiometer winder, comprising a winding form support, wire feeding means, means

for imparting relative rotation between said support and said feeding means, and means for imparting relative traversing motion between said support and said feeding means, master potentiometer means and means responsive to said master potentiometer, means for varying the speed ratio of said motions to produce a predetermined resistance function of wire wound on the winding form.

11. A potentiometer winder comprising in combination, a support adapted to carry a winding form on which resistance wire is to be wound, a device for feeding resistance wire to a winding form carried by said support, mechanism producing relative rotation between said support and said wire feeding means, lead screw means for producing relative traversing motion between the winding form support and the wire feeding means, means for driving both the winding mechanism and the lead screw means with an adjustable speed ratio, a master potentiometer with resistance varying means driven by the lead screw means, and a resistance comparator responsive to the relationship between the resistance of wire wound upon the winding form and the master potentiometer resistance for varying said speed ratio adjustment to vary the pitch to which wire is wound on the winding form for correcting deviations between the resistance function of the wire wound and that determined by the potentiometer.

12. Apparatus as in claim 11, wherein a linkage having a desired functional relationship is interposed between the lead screw means and the master potentiometer for causing a predetermined functional variation between the resistance of the master potentiometer and operation of the lead screw means in order to introduce such functional relationship into the resistance function of wire wound on the winding form.

13. In a coil winding machine, means for winding a wire on a support to form a resistance element, means for testing the resistance of the winding as the winding operation proceeds, and means controlled by said testing means for automatically changing the turn spacing to compensate for variations in the resistance of said wire.

14. In a coil winding machine, means for winding a wire in a predetermined winding space on a support to form a resistance element, means for testing the resistance of the winding as the winding operation proceeds, and means controlled by said testing means for varying the number of turns put in said winding space in accordance with the resistance of the wire.

15. In a coil winding machine, means for winding a wire on a support to form a resistance element, means for testing the resistance of the winding as the winding operation proceeds, said last means including a bridge circuit in which said winding forms one arm of the bridge, and means responsive to an unbalanced condition of said bridge circuit for automatically changing the spacing of the turns of said winding to compensate for variations in the resistance of said wire.

16. In a coil winding machine, means for winding a wire on a support to form a resistance element, means for testing the resistance of the winding as the winding operation proceeds, said last means including a bridge circuit in which said winding forms one arm of the bridge, a resistance the value of which increases linearly during the winding operation forming the opposite arm of said bridge, and means responsive to

an unbalanced condition of said bridge circuit and sensitive to the direction of unbalance for increasing or decreasing the spacing of the turns of said winding depending on whether the resistance of said wire is too high or too low.

17. In a coil winding machine, means for winding a wire on to a supporting element to form a coil thereon, and means for spacing the turns of said coil apart as the coil is wound, said means including an element which is adapted to produce a predetermined varying spacing and which is readily interchangeable with a similar element adapted to produce a different predetermined varying spacing.

18. In a coil winding machine, means for winding a wire on to a supporting element to form a coil on the element having a plurality of turns, wire guiding means for delivering the wire to said element, means for producing a relative movement between said element and guiding means to space said turns, and means including a cam for controlling said movement, said cam having an operative contour which is effective to produce a spacing which varies from turn to turn according to a predetermined law.

19. A method of winding a precision resistor having a resistance characteristic accurately predetermined by that of a reference standard comprising, winding resistance wire on a card to form a resistor, continuously comparing the resistance value of at least a portion of said resistor during winding with that of a corresponding variable portion of the standard, continuously modifying the unit dimensions of said resistor in response to deviations in the resistance value of said portion thereof from that of said portion of the standard, and introducing a non-linear factor into said comparison to impart a predetermined resistance-displacement characteristic to the resistor.

20. Apparatus for winding a precision electrical element having an electrical characteristic accurately predetermined by that of a reference standard comprising, means for winding a conductor to form an electrical element, means for continuously comparing the value of said electrical characteristic of at least a portion of said element during winding with that of a corresponding variable portion of the standard, means responsive to deviations in the value of said characteristic of said portion of said element from that of said portion of said standard for continuously controlling the action of said winding means to modify the unit dimensions of said element, and cam means for modifying the action of said comparing means to impart a predetermined electrical resistance-displacement characteristic to the element.

21. Apparatus for winding a precision resistor having a resistance characteristic accurately predetermined by that of a reference standard comprising, actuating means for winding resistance wire on a card to form a resistor, actuating means including an element for deriving from said reference standard an effect representative of resistance from point to point thereof, means for continuously comparing said effect with a corresponding effect derived from the resistor during winding, means responsive to the difference of said effects for continuously controlling the action of said winding means to modify the unit dimensions of said resistor, and cam means for modifying the action of said comparing means to impart a predetermined resistance-displacement characteristic to the resistor.

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22. Apparatus for winding a precision resistor having a resistance characteristic accurately predetermined by that of a reference standard comprising, means for winding resistance wire on a card to form a resistor, means for continuously comparing the resistance value of at least a portion of said resistor during winding with that of a corresponding variable portion of the standard, means responsive to deviations in the resistance value of said portion of said resistor from that of said portion of said standard for continuously controlling the action of said winding means to modify a unit dimension of said resistor, and cam means for modifying the action of said comparing means to impart a predetermined resistance-displacement characteristic to the resistor.

23. Apparatus for winding a precision resistor having a resistance characteristic accurately predetermined by that of a reference standard comprising, actuating means for winding resistance wire on a card to form a resistor, actuating means and an adjustable contact actuated thereby for continuously varying the resistance value of said standard, an electrical bridge including said resistor and said standard, means responsive to an unbalance of said bridge for continuously controlling the action of said winding means to modify a unit dimension of said resistor, and cam means included in one of said actuating means for imparting a predetermined

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resistance-displacement characteristic to the resistor.

24. Apparatus for winding a precision resistor having a resistance characteristic accurately predetermined by that of a reference standard comprising, a winding mechanism including means for winding resistance wire on a card and advancing means for producing relative transverse movement between said card and said feeding means to form a resistor, means for continuously comparing the resistance value of at least a portion of said resistor during winding with that of a corresponding variable portion of the standard, means responsive to deviations in the resistance value of said portion of said resistor from that of said portion of said standard for developing a control effect, and means responsive solely to said control effect for actuating one of said winding mechanism means, whereby upon failure of said control effect, normal winding of a resistor is interrupted.

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