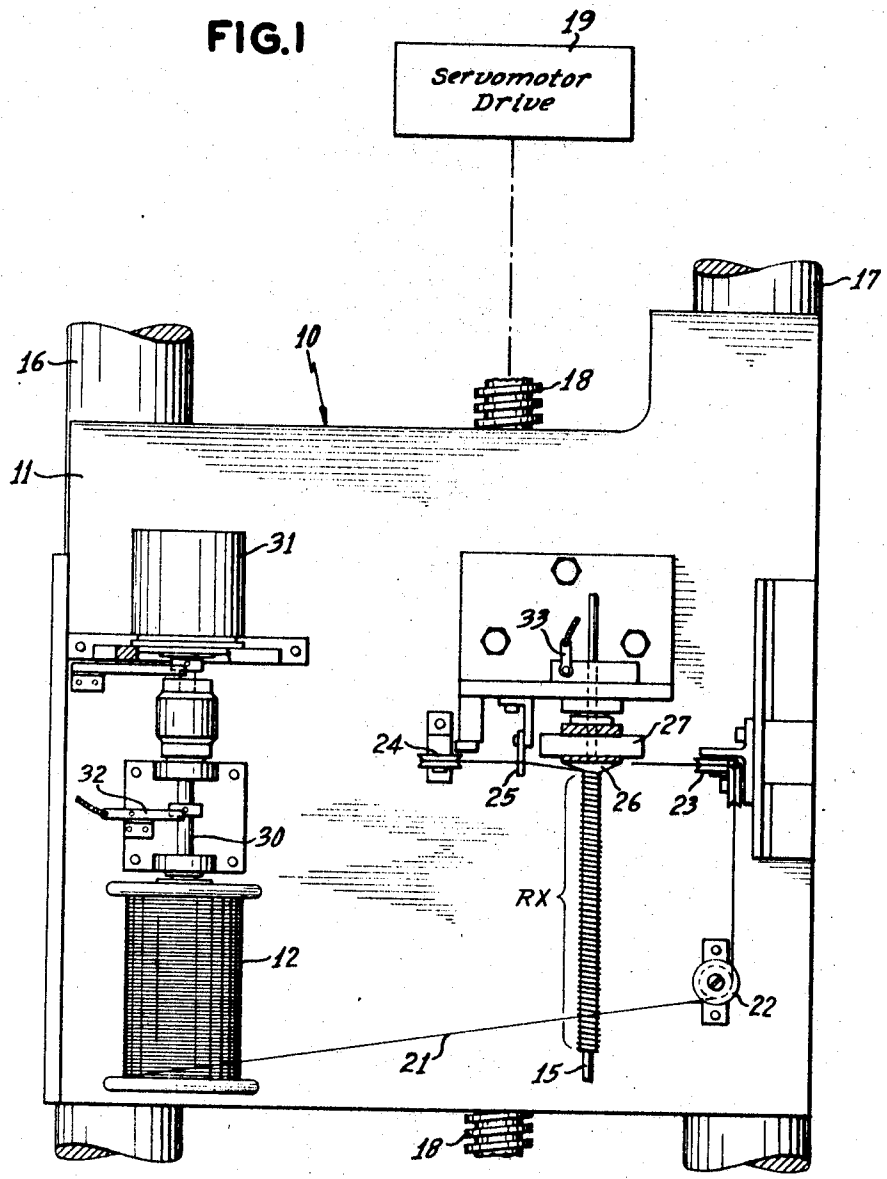
May 20, 1969 C. F. KEZER ET AL 3,445,071

METHOD AND APPARATUS FOR WINDING A PRECISION RESISTOR

Filed June 14, 1967 Sheet 1 of 3

FIG. 1



METHOD AND APPARATUS FOR WINDING A PRECISION RESISTOR

Filed June 14, 1967

FIG. 2

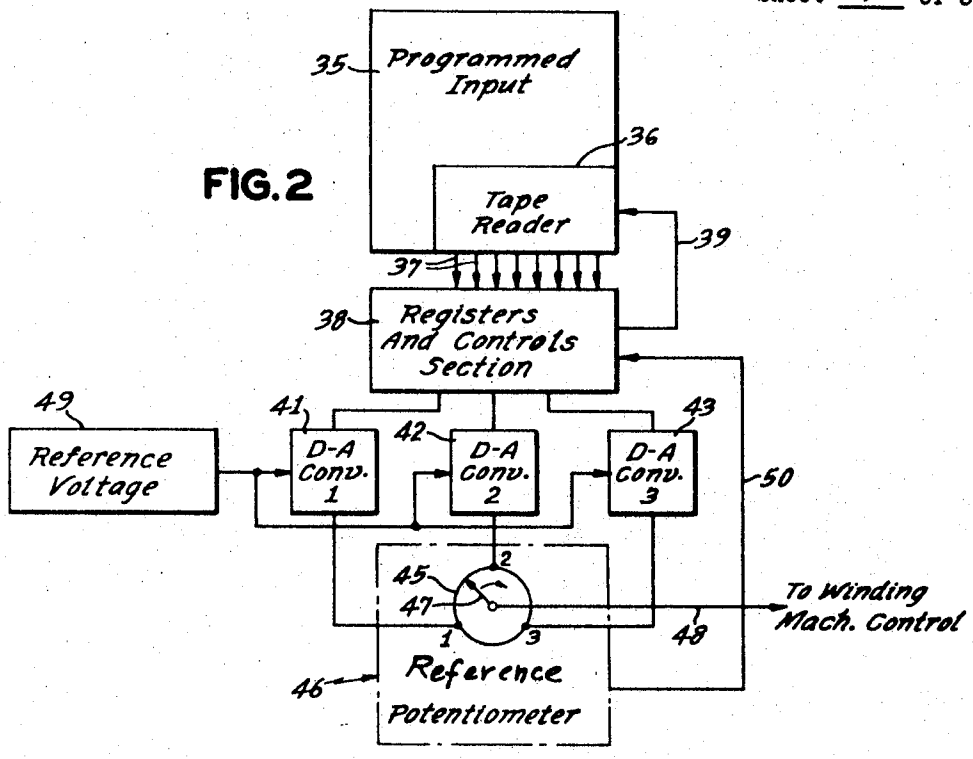


FIG. 3

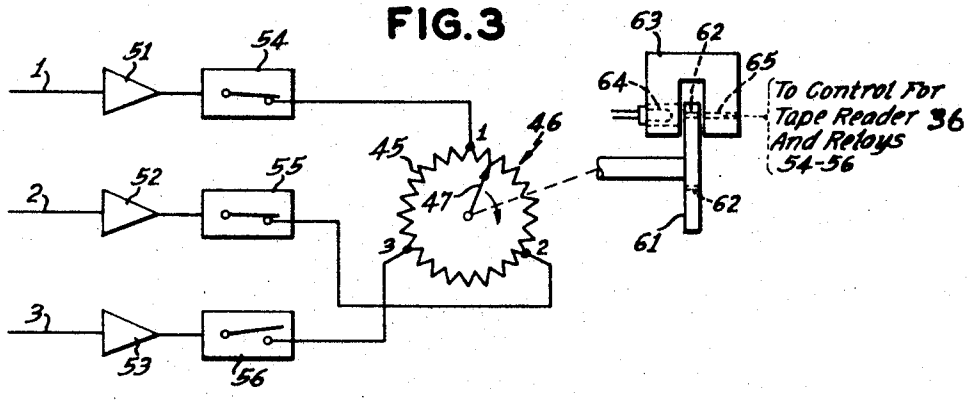
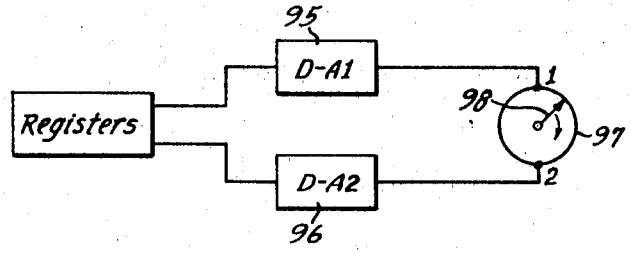


FIG. 7



METHOD AND APPARATUS FOR WINDING A PRECISION RESISTOR

Filed June 14, 1967

FIG. 4

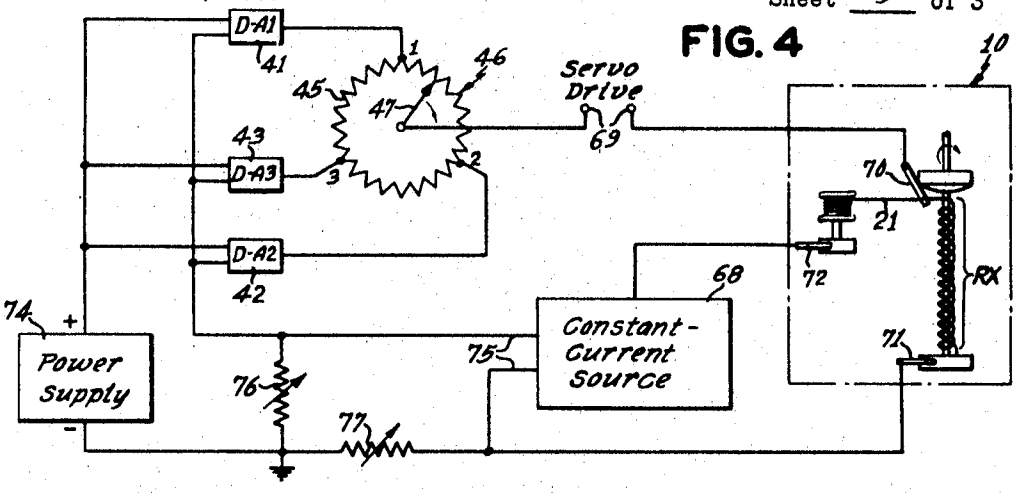


FIG. 5

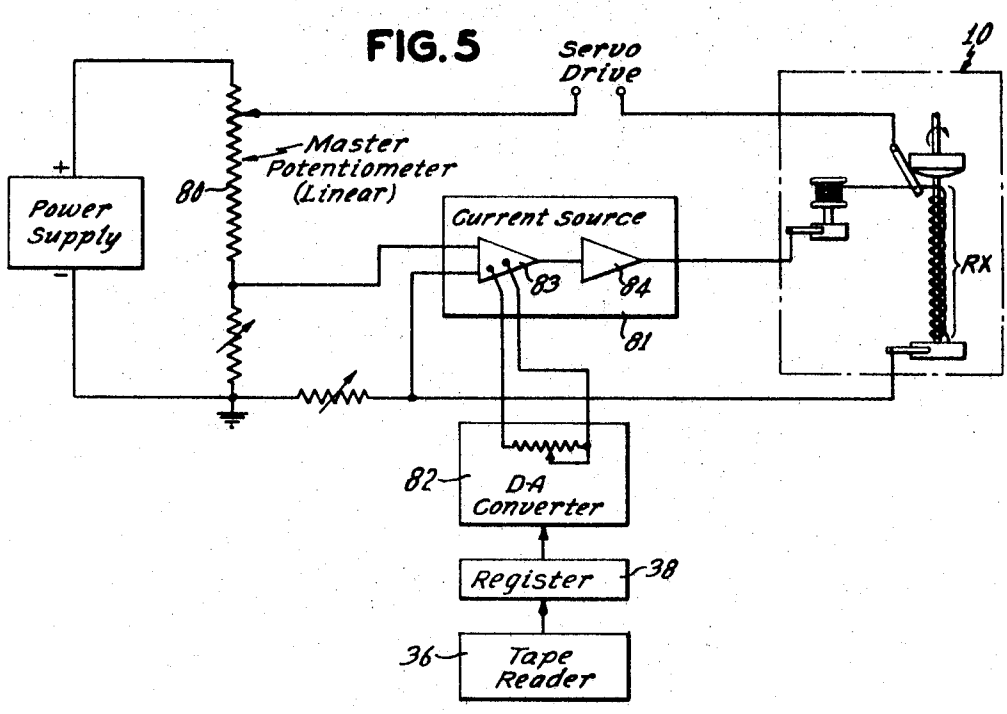
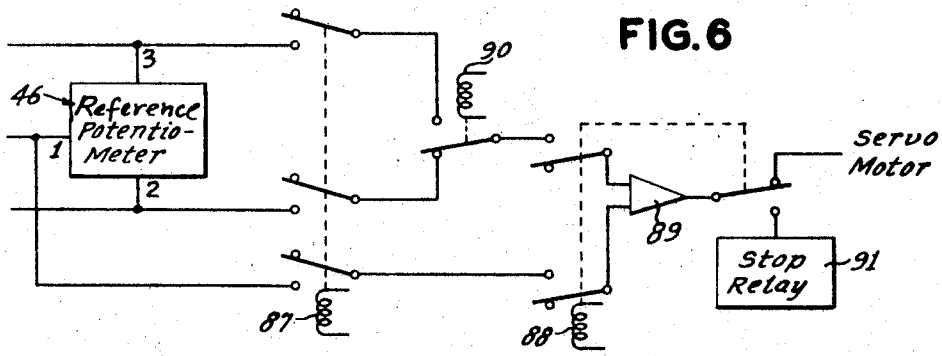


FIG. 6



United States Patent Office 3,445,071
Patented May 20, 1969

3,445,071

METHOD AND APPARATUS FOR WINDING A PRECISION RESISTOR

Charles F. Kezer, Mineola, and Thomas P. Zingarelli II, New York, N.Y., assignors to Litton Industries, Inc., Beverly Hills, Calif., a corporation of Delaware

Filed June 14, 1967, Ser. No. 646,019
Int. Cl. B65h 81/06; G01v; G05f
U.S. Cl. 242—7.03 12 Claims

ABSTRACT OF THE DISCLOSURE

A method and apparatus for controlling a winding machine for making the resistor element of a potentiometer. The apparatus employs a programming arrangement having signal-sensing and -storage means for control signals. In the illustrative embodiment, the stored digital signals encoded on tape are converted into analog signals which are utilized to control the spacing of the turns of resistance wire which forms the resistor being wound on the winding machine, in order to obtain a desired spatial-resistance characteristic. Changes in the functional characteristics of the wound resistor are effected by using a different input element (tape). The apparatus also includes checking means to enable correction of any malfunction of the control system.

This invention relates to methods and apparatus for programming the winding operation of a machine for winding the precision resistor element of a potentiometer, and for guarding against improper operation of the control apparatus.

It is an object of the invention to improve the programming of a precision winding machine that may be used for winding the resistor element of a potentiometer, to simplify the time-consuming method of programming the winding machine as practiced heretofore, and to eliminate human error in the operation of the machine.

A more specific object of the invention is the provision, in the programming arrangement for a winding machine of this character, of signal-sensing and -storage means, such as a punched tape and tape reader, for controlling the programming of the machine. In this manner the programming may be changed readily to alter the functional characteristics of the resistor being wound by merely substituting control tapes in the programming unit. Hitherto the programming required manually shifting and wiring a large number of tap connections on a master or reference standard potentiometer.

Still another object of the invention is to provide a simple and effective arrangement for detecting malfunctioning of the programmed control system of a winding machine.

For a clearer understanding of the invention, and other objects and advantages thereof, reference may be made to the illustrative embodiments of the invention shown in the accompanying drawings, wherein

FIG. 1 is a plan view of a typical resistor winding machine in general use which is adapted to be controlled by a programming arrangement according to the invention;

FIG. 2 is a schematic diagram of the program console embodying the invention for controlling the servo drive mechanism of the winding machine;

FIG. 3 is a view, partially schematic, showing the interconnections between the control section of the program unit and the reference or control potentiometer;

FIG. 4 is a similar view showing the interconnection of the reference potentiometer, the winding machine and a servomotor input circuit;

FIG. 5 is a view similar to FIG. 4 showing a modification;

FIG. 6 is a diagrammatic view of a system for checking the program unit for malfunctioning condition; and

FIG. 7 is a view similar to FIG. 3 of a modification in which the control potentiometer is provided with only two taps.

Referring to the drawings, FIG. 1 shows a precision winding machine used in practice and similar to that shown and described in the patent to J. R. Altieri, No. 3,203,633, and assigned to the assignee of the present invention. The disclosure of said patent is incorporated herein by reference. The winding machine shown in the drawing merely illustrates by way of example a well-known winding machine to which the control system of the invention may be applied and the invention is not limited to this particular type of winding machine.

As shown, the winding machine employs a travelling carriage **10** which includes a horizontal base plate **11** on which are supported a spool of resistance wire **12** and suitable wire-guiding means in cooperative relation to an insulating mandrel **15** on which the resistance wire is wound to form a precision resistor for a potentiometer. Other parts of the machine, including the controlled motor drive, are also well-known and are illustrated in detail in the prior patent to A. S. J. Lee, No. 2,989,256, the disclosure of which is incorporated herein by reference. The carriage **10** is supported for transverse movement on two parallel guide rails **16** and **17**, the carriage being fed along the axis of the mandrel **15** by a lead screw **18** connected to the servomotor drive **19** which may be similar to that described in the Lee patent. The mandrel **15** is restrained against longitudinal movement and rotated at constant speed. Since the rate of feed of the carriage **10** is proportional to the rate of rotation of the lead screw **18**, the spacing of the resistance wire wound on the mandrel **15** is dependent on the relation between the rotative speeds of **18** and **15**. Thus the servomotor drive for the winding machine controls the spacing between the turns of wire on the mandrel **15** in accordance with the desired functional characteristics of the resistor being wound, the variation being controlled by a programmed control system including a control potentiometer as will be described. During the winding operation, the resistance wire **21** is unwound from the spool **12** and passes over guide pulleys **22**, **23** and **24**, and over the guide bar **25** to engage the tip end of the nose piece **26** through which the mandrel **15** is fed. The nose piece **26** is part of a hollow mandrel guide **27** embracing the rotating mandrel **15** and serving to accurately position the point of lay of the wire as it is fed onto the winding form or mandrel **15**, as described in detail in the above-mentioned patents. The nose piece **26** also provides electrical contact with the wire **21** so that the resistance Rx of the wound portion of the resistor may be continuously checked as the winding operation proceeds.

The wire spool **12** is preferably to a rotatable spool shaft **30** connected to a brake motor **31** to maintain a predetermined tension in the resistance wire being wound on the mandrel **15**. A brush **32** is provided in contact with the shaft **30** to supply current to the wire **21** during the winding operation. A connection may be made to the nose piece **26** and terminal **33** whereby the potential drop across the varying resistance Rx may be compared with the control potential derived from the control or reference potentiometer during the winding operation to control the servomotor drive for obtaining the desired functional characteristics in the finished product.

The servomotor drive **19** may consist of low-speed and high-speed servomotors controlled by the connection to the reference potentiometer to maintain a balance between the adjustment of said potentiometer and the po-

tential drop across the resistance Rx similar to the control described in the above-mentioned Lee patent. However, in prior controls as exemplified by said patent, the programming arrangement includes a master reference potentiometer containing a great many tap connections which must be precisely located and shifted in position when the winding machine is to be operated to produce resistors having different electrical characteristics. For example, in practice a 40-turn, 80-tap potentiometer has been commonly used. Making the tap connections is a laborious and time-consuming operation subject to human error, resulting in reject or defective units.

In accordance with the present invention, the programmed control system consists of signal-sensing and -storage means for a multiplicity of control signals, such as a punched tape and a tape reader, and means for successively applying corresponding control voltages to spaced points or taps on a linear reference potentiometer with fixed taps. FIG. 2 illustrates essentially the novel control system. Referring to this figure, the program console comprises a programmed input unit **35** including a punched tape and a tape reader **36** connected through conductors **37** to a register and control section **38**. The input unit **35** constitutes a control signal-sensing and -storage means. The control section **38** is provided with a connection **39** for stepping the tape reader **36** to read out successive blocks of stored control signals. The tape reader **36** may, for example, be designed for standard eight-channel punched tape containing stored signals representing commands, data and instructions for self-system checkout. A suitable tape reader mechanism is the model 2500 made by Digitronics Corporation of Albertson, Long Island, N.Y. The programming is achieved by a block format and in a typical system each block consists of digitized signals representing at least one predetermined voltage or potential followed by the end of block command. Once started the tape reader reads at maximum speed, programming the tap voltages as required.

It will be understood that the conventional control system for a servo-controlled winding machine of this type includes means for continuously measuring the resistance of the wound portion of the resistor being formed on the winding machine and a master reference potentiometer having fixed potential taps and a movable contact or slider which is synchronized with the winding machine; the potential drop in the wound portion of the resistor being compared with the reference potential from the master potentiometer, and the difference between said potentials being utilized to continuously control the servomotor drive to obtain the desired functional characteristics in the wound element. In order to obtain control potentials to control the winding operation, in accordance with the present invention, signal storage means is employed to store control signals which are converted to voltages or potentials applied in succession at predetermined times to a reference potentiometer having two or more fixed taps.

In the embodiment shown in FIG. 2 the stored control signals in the register section **38** having three output channels are converted from digital to analog signals in the D/A converters **41**, **42** and **43**. A source **49** of reference voltage is connected to the D/A converters. Obviously the control signals may be stored in any suitable manner and, if stored in analog form on a tape or other storage medium, the D/A converters would not be required. The output potentials of the respective converters are impressed upon the equally spaced taps Nos. **1**, **2** and **3** of the linear resistance **45** of a reference potentiometer **46**, which corresponds to the master potentiometer used heretofore. The principal advantages of this control system are that a simple reference potentiometer having a few fixed taps replaces the multiturn master potentiometer having a multiplicity of taps as used in the prior art, and the functional characteristics of different resistance elements being wound may be varied by substituting different input elements such as punched tapes instead of modifying the many tap connections to the master potentiometer whenever the winding machine is to be operated to form a different resistance element. Thus the system is more reliable and much simpler to set up. Furthermore, the length of the resistance element to be wound may be changed readily merely by changing the gear ratio in the drive connection from the winding machine to the movable contact member of the master potentiometer.

In order to achieve the required level of system accuracy, flexibility and speed, a relatively large quantity of numerical data and alphabetic commands must be stored and utilized by the control console in a short period of time. This requirement is met by the present system involving the use of computer-type logic for quick access to control data. After the program input console has been prepared, the operator merely closes a start switch which advances the tape to the initial start point. The servo drive for the winding machine is then turned on and the differential or error voltage between the master potentiometer and the resistance Rx of the wound portion of the resistor then controls the servo drive of the winding machine to change the pitch of the winding as required. After the movable contact or slider **47** of potentiometer **46** has advanced to a predetermined point, the tape advances to program a different potential on one of the taps of potentiometer **46**, and this cycle is repeated until the winding is finished.

The register and control section **38** may be of any well known type, depending upon the character and functioning of the control signal storage. In the system illustrated employing punched tape by way of example, the stored control signals are set up in conventional registers which apply corresponding signals through the D/A converters in the three signal channels to the potentiometer **46** in timed relation to the winding operation and the consequent advance of the movable contact or slider **47**. In practice, a voltage divider is utilized in each channel which may be a relay-operated voltage divider such as the model RVD–105 manufactured by Julie Research Laboratories, New York, N.Y. By the use of conventional registers and amplifiers, the voltage ratio received from the tape in serial digit form is converted by means of the registers to parallel digit form for transmission to the code converters **41**, **42**, **43**, and the taps on the potentiometer **46**. The amplifiers in each control signal channel may be Philbrick operational amplifiers, model USA–3, made by George A. Philbrick Researches, Inc. of Boston, Mass. Obviously various other code storage, readout and converter arrangements known in the art may be employed to apply the desired successive control voltages at proper intervals to the taps of the potentiometer **46**.

Referring to FIGS. 3 and 4, the three control channels are shown as including operational amplifiers, **51**, **52** and **53**, and relays **54**, **55** and **56** in the respective channels to connect and disconnect the reference voltages as the programmed input is stepped and the slider **47** advances from one tap to the next on resistance element **45**. The stepping functions may be performed in any suitable manner. As shown, the shaft of the slider **47** is connected to an apertured disc **61** having three equally spaced apertures **62**. The disc **61** cooperates with a photoelectric impulse generator **63** which may consist of a lamp **64** and a photosensitive pickup element **65** arranged on opposite sides of the disc **61**. As the disc **61** rotates, the apertures **62** are brought into registry with the light from the lamp **64** to generate control pulses in timed relation to the rotation of the slider **47**. These control pulses may then be used in an obvious manner to control the tape reader **36** to step the tape, as well as to reset the registers in the control section **38** and selectively operate relays **54**, **55** and **56**. When slider **47** is in the position shown in FIG. 3, the contacts of relays **54** and **55** connect channels **1** and **2** to taps **1** and **2** on resistance **45**; subsequent-

ly channels 2 and 3 are connected to taps 2 and 3, and so on, by relays 54–56.

FIG. 4 illustrates the manner in which the potentiometer 46 is substituted for the master potentiometer in the control system of the prior art, for example as shown in the patents referred to above. As indicated, the power supply 74 may be employed as a source of reference potential for the D/A converters 41, 42 and 43. The control for the winding machine includes a constant-current source 68 and terminals 69 of the servomotor drive mechanism which are explained in detail in the Altieri patent and require no further description. The constant-current source 68 is a high-gain amplifier with feedback to maintain a constant output current irrespective of changes in the resistance of the load circuit. A suitable current source of this type is the Model CS–11 Precision Current Source manufactured by North Hills Electronics, Inc., of Glen Cove, Long Island, N.Y. The resistance Rx of the wound portion of the resistance element is measured by contact brushes 70 and 71 in series with one of the terminals 69 and the power supply 74. The servomotor drive responds to the differential voltage between the terminals 69. The elements 72 to 77 may be similar to the corresponding elements of the control system described in the Altieri patent, and the control of the servomotor drive will be obvious to those skilled in the art, even without reference to the prior patents mentioned. The circuits and apparatus shown in FIGS. 3 and 4, with the exception of potentiometer 46 and its input control circuits, are conventional.

Instead of using a constant-current source in series with the resistance element being wound, and a signal input arragement for the reference standard as described above and shown in FIGS. 1 to 4, a linear master potentiometer of the usual type may be used with a current source of the same type as source 68 but having its output current varied to obtain either linear or non-linear functional characteristics of the resistor under the control of the program unit, thus eliminating the requirement for a multiplicity of taps on the master potentiometer. This modification is shown in FIG. 5, which is similar to FIG. 4 except that the master potentiometer 80 is a simple linear potentiometer which can be used for winding either linear or non-linear resistor elements by variation of the output current from an adjustable constant-current source 81, such as the Current Source of North Hills Electronics, Inc., referred to above. In this modification the tape reader 36 and a register 38 may be similar to the tape reader and register described above or any other suitable means for generating the control input voltages. A D/A converter 82 is used to generate a potential varying in amplitude in accordance with the signal input and operative to vary the input of the operational amplifier 83 in the current source unit and thereby vary the output current of the source 81. The current source 81 may also include a power amplifier 84. It will be apparent that the functional characteristics of the resistor element being wound may be varied in a predetermined manner under the control of the program unit in response to variations in the output current of source 81. Thus the same result is obtained without varying the potentials applied to the taps of the reference potentiometer.

In order to detect malfunctioning of the programming and control system, the test or checking circuit shown in FIG. 6 may be employed. For the checking operation, the programming system is adjusted to advance a test tape three blocks during each test-signal cycle and the three blocks on the test tape program the same voltage ratio into each test channel. Thus the potentials applied to the taps of the master potentiometer 46 are equal during each successive cycle of the test procedure. The contacts of three relays 87, 88 and 90 are connected to control the circuit extending from each of the input channels. Relays 87 and 88 are initially energized and apply the output voltages of channels 1 and 2 to the amplifier 89. The relay 90 is then energized to compare the voltage on channel 1 with the voltage on channel 3. If the difference between the adjacent tap voltages at any time exceeds a predetermined amount, a stop relay 91 is energized to stop the feeding of the tape, which indicates that the register and control system is out of adjustment or not operating properly. The programming system is then serviced to repair or replace any defective element.

Obviously the potentiometer 46 may be provided with only two taps or more than three taps, with a corresponding number of input channels. FIG. 7 illustrates the modification wherein two D/A converters 95 and 96 are connected to the two taps of the resistance element 97 of the master potentiometer. The circuit is otherwise the same as shown and described above in FIGS. 1 to 4. In case more than three channels are employed, a corresponding number of equally spaced taps is provided on the master potentiometer.

It will be seen that the invention provides a programming method for a winding machine which is superior to the existing laborious and painstaking programming method. It is easier to set up for the production of different resistance elements and the possibility of human error is eliminated. The apparatus used comprises standard electronic and mechanical devices which are readily available, interconnected in a novel manner in accordance with the invention.

What is claimed is:

1. An apparatus for winding a precision resistor for a potentiometer, comprising
   - a servo-controlled winding machine having a servomotor drive mechanism, and
   - means including a reference potentiometer for programming the winding of the resistance wire by said winding machine, said reference potentiometer having a movable contact connected to said servomotor drive mechanism and synchronized with the winding operation of said winding machine,
   - said programming means further including control signal sensing and storage means for a multiplicity of control signals, connected to said reference potentiomter for applying voltages corresponding to said control signals to the programming function.

2. An apparatus according to claim 1, in which said reference potentiometer has a plurality of taps along the resistance element thereof, and switching means is provided to connect control voltages corresponding to said stored control signals to said taps in timed relation to the progressive winding operation.

3. An apparatus for winding a precision resistor for a potentiometer, comprising
   - a servo-controlled winding machine,
   - means for continuously checking the resistance Rx of the wound portion of the resistor as it is formed,
   - means including a reference potentiometer for programming said winding machine, said programming means further including control signal sensing and storage means for a multiplicity of coded control signals, and
   - means for successively applying said control signals to said reference potentiometer to control the programming function.

4. An apparatus according to claim 3, in which said means for continuously checking the resistance Rx of the wound portion of the resistor includes a constant-current source in series relation with said wound portion, and the winding of the resistor is controlled by the relation between the potential drop across resistance Rx and a potential derived from said reference potentiometer.

5. An apparatus for winding wire to form a precision resistor for a potentiometer, comprising
   - a servo-controlled winding machine having a servomotor drive mechanism for an operating shaft of said winding machine,

a reference potentiometer for programming the winding of the resistance wire by said winding machine to form a resistor having the desired functional characteristics, said reference potentiometer having the movable contact thereof synchronized with the operating shaft of said winding machine,

means including the movable contact of said reference potentiometer for controlling said servomotor drive mechanism for the winding machine,

at least two taps on said reference potentiometer, and

means for applying control voltages to said taps on said potentiometer for brief successive intervals in timed relation to the progressive winding of the resistor being formed, to control the servomotor drive mechanism and thereby the spacing of the turns of wire on said resistor.

6. An apparatus according to claim **5**, in which control signals representing said control voltages are stored in digital form in signal-storage means and a digital to analog converter is connected between the signal-storage means and each tap on said reference potentiometer.

7. An apparatus according to claim **6**, in which said signal-storage means comprises a punched tape and a tape reader stepped concurrently with the advance of the movable contact of the reference potentiometer from one tap to another.

8. Apparatus for winding a precision resistor for potentiometers, in combination,

a servo-controlled winding machine in which the functional characteristics of the resistor being wound are controlled by varying the servo drive,

means for programming the operation of the servomotor, including a linear potentiometer having a plurality of equally spaced taps and a slider synchronized with the operation of the winding machine, said programming means further comprising control signal-sensing and storage means for multiplicity of control signals, and

switching means for connecting control signals from said signal-sensing and storage means in predetermined sequence to the taps on said linear potentiometer.

9. The method of controlling a winding machine for winding a resistor element with a predetermined spatial-resistance function, said winding machine including a servomotor drive mechanism and a reference potentiometer connected to said servomotor driving mechanism, comprising the steps of

storing control signals representing the functional characteristics of the resistor element to be wound on the winding machine, and

applying corresponding signals successively to said reference potentiometer during the winding operation to control the operation of the servomotor drive mechanism.

10. The method according to claim **9**, which includes the steps of storing the control signals on tape and stepping said tape in timed relation to the progress of the winding operation.

11. The method of controlling a winding machine for winding a resistor with a predetermined spatial-resistance function, said winding machine including a servomotor drive and programming means for controlling said servomotor drive, comprising the steps of

storing control signals representing the desired functional characteristics of the resistor, and

utilizing said control signals sequentially during the winding operation to control the servomotor drive.

12. In a servo-controlled winding machine for winding a resistor having a predetermined spatial-resistance function, in which the programming console includes a plurality of control-signal input channels and corresponding voltage output circuits, the method of checking the operativeness of the system which comprises the steps of

operating the programming console through the steps of a normal cycle,

applying the same signal input to all said input channels during each step of the cycle, and

stopping the sequential operation of the system upon the occurrence of a difference exceeding a predetermined amount between any two voltages in the output circuits.

References Cited

UNITED STATES PATENTS

2,964,252	12/1960	Rosenberg	242—9
2,989,256	6/1961	Lee	242—9
3,128,956	4/1964	Schumann	242—9
3,166,104	1/1965	Foley et al.	242—9 XR
3,181,061	4/1965	Schneider	324—62
3,203,633	9/1965	Altieri	242—9
3,237,657	3/1966	Elvers et al.	242—9 XR

BILLY S. TAYLOR, *Primary Examiner.*

U.S. Cl. X.R.

29—593, 618; 242—7.12; 318—28; 324—62

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,445,071 Dated May 20, 1969

Inventor(s) Charles F. Kezer and Thomas P. Zingarelli II

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 57, after "preferably" insert--clamped--.

Column 6, lines 42 and 43, "potentiomter" should read--potentiometer--.

Column 7, line 31, "servo" should read--servomotor--; line 37, after "for" insert--a--.

SIGNED AND
SEALED
SEP 2 - 1969

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents