Nov. 29, 1955 J. L. BOWER 2,725,199

AUTOMATIC POTENTIOMETER WINDER

Filed May 28, 1951 2 Sheets-Sheet 1

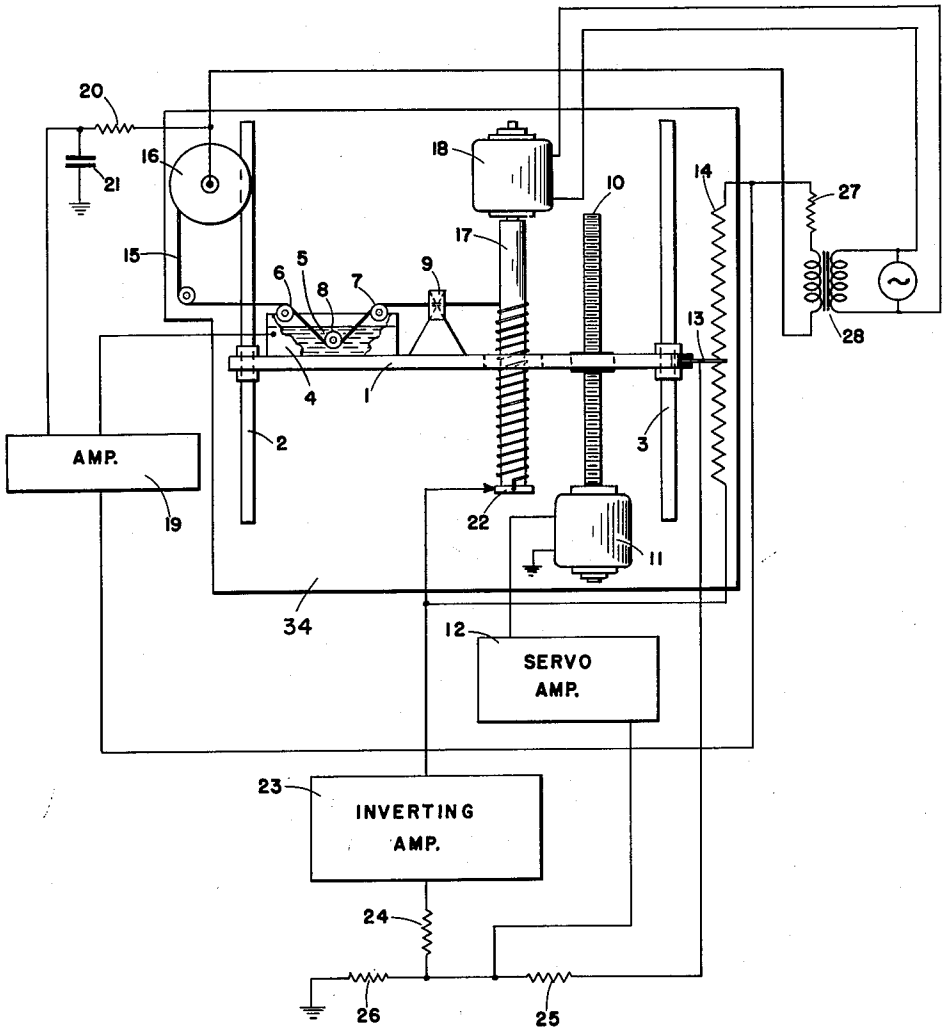

FIG. 1

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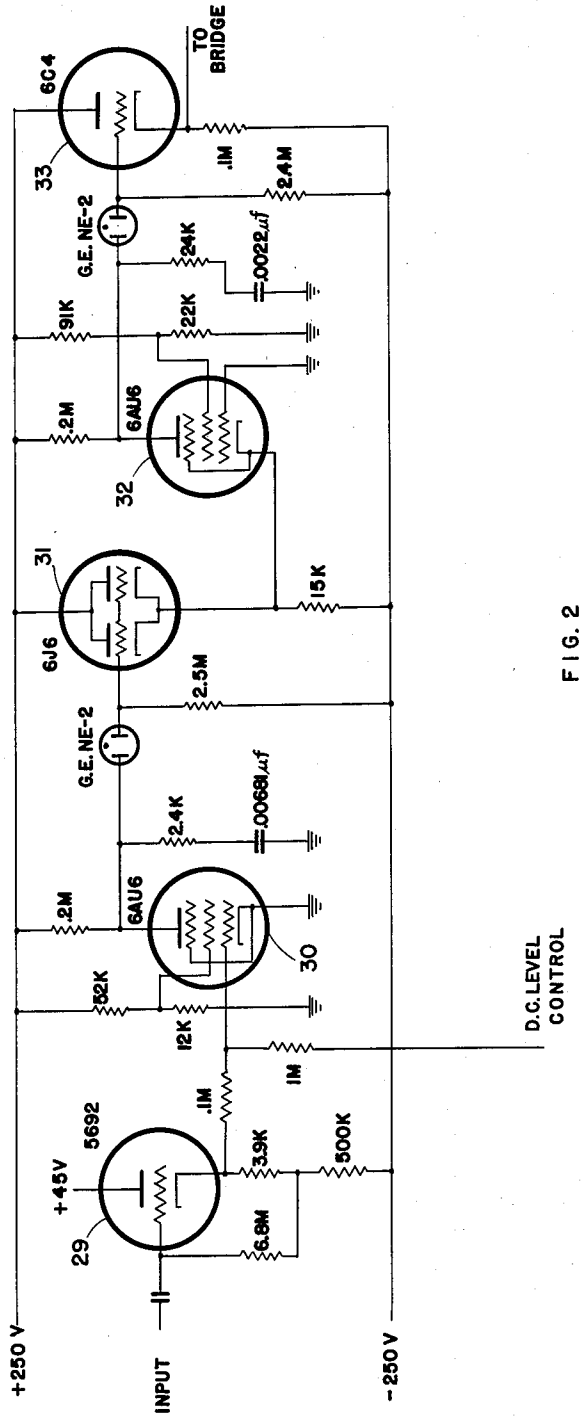

FIG. 2

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AUTOMATIC POTENTIOMETER WINDER

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9 Claims. (Cl. 242—9)

This invention relates to potentiometers, and particularly to apparatus for winding such potentiometers automatically with high resolution and high resistance per unit length.

Automatic potentiometer winders devised in the past have not been capable of winding insulated potentiometer wire in a manner which takes into account variations in resistance along the length of the wire. Further, potentiometers wound of bare wire by methods which did take such resistance variations into account have left much to be desired as to resolution and maximum resistance per unit length because of the space necessarily left between turns to provide the necessary insulation. It is therefore an object of this invention to provide apparatus for winding potentiometers automatically with insulated wire.

It is another object of this invention to provide apparatus for automatically winding potentiometers so that they have identical resistance versus displacement characteristics.

It is another object of this invention to provide an automatic potentiometer winder for winding potentiometers of high resolution.

It is another object of this invention to provide potentiometers of high resistance per unit length.

It is another object of this invention to provide an automatic potentiometer winder adapted to wind a nonlinear potentiometer which is the duplicate of any other nonlinear potentiometer.

It is another object of this invention to provide an automatic potentiometer winder adapted to wind a potentiometer which is nonlinear and whose resistance at any point is a predetermined function of the corresponding resistance of any linear or nonlinear potentiometer.

Other objects of invention will become apparent from the following description taken in connection with the accompanying drawings, in which

Fig. 1 is a schematic drawing of the invention; and

Fig. 2 is a circuit diagram of the high input impedance amplifier of this invention.

Referring to Fig. 1, a carriage **1** supported on tracks **2** and **3** supports container **4** containing fluid bath **5** and supporting rollers **6**, **7**, and **8**. Jewel **9** is also supported on carriage **1** which is movable along tracks **2** and **3** by lead screw **10**. Lead screw **10** is rotated by motor **11** driven by servo amplifier **12**. Also attached to carriage **1** is slider arm **13** of master potentiometer **14** which is fixed and does not move with carriage **1**. Wire **15** wound on spool **16** passes through fluid bath **5**, passing over rollers **6** and **7** and under roller **8**. The wire leads through jewel **9** and is wound on mandrel **17** which is turned by motor **18**. Motor **18**, motor **11**, tracks **2** and **3**, and master potentiometer **14** are supported upon base **34**. The input of high input impedance amplifier **19**, more fully shown in Fig. 2, is taken from container **4** which is of conducting material. The D.-C. level control for high input impedance amplifier **19** is taken from the end of wire **15** on spool **16** through resistance **20** with capacitor **21** connected as a low pass filter. Wire **15**, which is the resistance wire with which the potentiometer is wound, is connected at its end to slip ring **22** which is conductively connected to the lower end of master potentiometer **14** and to the input of inverting amplifier **23**. The output of amplifier **23** is connected by resistance **24** to a junction with resistances **25** and **26** which are connected to slider **13** and ground, respectively. The upper

end of master potentiometer **14** is connected to the output of amplifier **19** and by resistance **27** to the secondary of transformer **28**. The secondary of transformer **28** is in turn connected to the end of wire **15** which is wound on spool **16**.

Amplifier **19** is shown in detail in Fig. 2. Container **4** is connected through a capacitor to the grid of triode **29**, which is a cathode follower. The output of triode **29** is amplified in voltage amplifier **30** and applied to cathode follower **31**. The output of cathode follower **31** forms the input to voltage amplifier **32**. The output of voltage amplifier **32** forms the input of cathode follower **33** whose output is connected as shown in Fig. 1 to master potentiometer **14**.

This apparatus may be used for winding a potentiometer upon mandrel **17**, which may be of variable cross-sectional area and shape, in such a manner that the resistance at any point on the potentiometer bears any predetermined ratio to the resistance taken at a similar point on the master potentiometer. For example, referring to Fig. 1, let it be required to wind upon mandrel **17** a potentiometer which at any point has a resistance proportional to the resistance at a similarly displaced point on master potentiometer **14**. Wire **15** is attached to slip ring **22** and alternating current is applied to the primary of transformer **28**. Likewise, current is applied to motor **18** which begins winding wire **15** on mandrel **17**. As the resistance of the lower portion of master potentiometer **14** differs from the resistance of the wire wound upon mandrel **17**, a signal appears at the junction of resistances **24**, **25**, and **26**, is amplified in servo amplifier **12**, and used to drive servo motor **11** to advance or retard carriage **1** by means of lead screw **10**. Lead screw **10** is turned until the resistance of the wire wound on mandrel **17** is equal to the resistance of the master potentiometer between slider **13** and the lower end thereof. The function of slider **13**, therefore, is to sample the resistance of master potentiometer **14** at each point to which the slider is moved. Wire **5** may vary in cross-section enough to make a potentiometer of which it is wound nonlinear if no automatic control were employed. Therefore, the spacing of the turns of wire on mandrel **17** is varied to compensate for small variations in resistance of the wire due to variations in cross-section or variations in composition of the wire. From the figure, it may be seen that the resistances of the wire wound on mandrel **17**, the resistance of the lower part of the master potentiometer, and resistances **24**, **25**, and **26** form a bridge, the resistance of the master potentiometer and the wound potentiometer forming one arm of the bridge and resistances **25** and **26** forming the other arm of the bridge. The two arms of the bridge are joined at their center points by inverting amplifier **23** and resistance **24** so that when the resistance of master potentiometer **14** bears the same relation to the sum of the resistance of master potentiometer **14** and the resistance of the wound potentiometer as resistance **24** bears to resistance **25** less resistance **24**, the input to servo amplifier **12** has no alternating current component because the output of inverting amplifier **23** exactly balances the potential of the junction between resistance **25** and resistance **24**. Thus, if the master potentiometer is nonlinear, the potentiometer wound by this apparatus upon mandrel **17** will likewise be nonlinear in the same relationship. Furthermore, the potentiometer wound upon mandrel **17** may be made to bear any predetermined ratio to the master potentiometer, which ratio is determined by the relation of resistance **25** to resistance **24**. Therefore, linear or nonlinear potentiometers proportional to any master potentiometer according to any predetermined ratio may be wound by this apparatus.

In order to assure that inverting amplifier **23** will maintain the junction point between resistances **24** and **25** at A.-C. ground it is necessary that wire **15** be held at

ground potential where it is wound upon mandrel 17. Since the wire being wound upon the potentiometer is, in general, insulated, direct contact with the wire at this point cannot be made. Therefore, liquid bath 5, which may consist of water, is provided with conducting container 4 to form a capacitive connection with the wire at a point adjacent to where the wire is being wound upon mandrel 17. The signal from this capacitive connection is fed to high input impedance amplifier 19 whose output signal is adjusted to supply a potential to the upper end of master potentiometer 14 such that wire 15 at the point where it is being wound upon mandrel 17 will be held at ground potential. Since it is desired that amplifier 19 operate near the center of its linear range and supply relatively high level signals from a very weak input from capacitive container 4, D.-C. level control is supplied from the end of wire 15 which is wound upon spool 16. A low pass filter, consisting of resistance 20 and capacitor 21 as shown in the figure, is used to supply this D.-C. level control. The input to amplifier 19 is connected through a capacitor so that in case wire 15 is poorly insulated, the D.-C. potential of the wire does not affect the grid bias of the first stage of amplifier 19.

Alternatively, lead screw 10 can be driven by motor 18 so that carriage 1 is advanced at a uniform rate, with mandrel 17 being driven by servo motor 11 and amplifier 12.

Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. Apparatus for winding a potentiometer with unbroken insulated resistance wire so as to be precisely proportional to a master potentiometer comprising a rotatable mandrel restrained against longitudinal movement, means for paying said insulated resistance wire onto said mandrel as it rotates, capacitive detector means associated with said paying means for sensing the potential of said insulating wire at the point where said wire is being wound on said mandrel without piercing the insulation of said wire, electronic servo means responsive to said capacitive detector means and connected to adjust the potential applied across said resistance wire in a manner to maintain said wire at the point where said wire is being wound on said mandrel at substantially ground potential, contact means associated with said paying means for sampling the resistance of said master potentiometer, means for advancing said paying and sampling means along said mandrel and said master potentiometer at a uniform rate, and means for varying the speed of rotation of said rotatable mandrel in response to the difference between the resistance of the wire wound on said mandrel and a predetermined function of the resistance detected by said sampling means on said master potentiometer to thereby wind a potentiometer precisely proportional to said master potentiometer.

2. In an automatic potentiometer winder of the type in which the spacing of the turns of insulated resistance wire wound on a mandrel is varied in response to the difference between the resistance of a master potentiometer and the resistance of the wire wound on said mandrel so as to maintain proportionality between the resistance at corresponding points on the potentiometer being wound and the master potentiometer, means for continuously sensing the resistance of the wire wound on said mandrel without breaking the insulation around said wire comprising capacitive means for sensing the departure from ground potential of said insulated resistance wire where it is being wound on said mandrel, means for applying a constant alternating current to the wound end of said potentiometer being wound, and means for applying a signal to said wound end of said potentiometer being wound in response to said sensing means of a polarity and magnitude to maintain said resistance wire where it is being wound on said mandrel at substantially ground potential whereby the potential of said end is a function of the resistance of the wire wound on said mandrel.

3. An apparatus for accurately sensing the resistance of an insulated resistance wire between one end and a point along its length comprising capacitive detector means sensitive to the A.-C. potential of said insulated wire at said point without piercing the insulation of said wire, amplifier means responsive to said detector means connected to apply a signal to said resistance wire through the ends thereof of a phase and amplitude to maintain said point at A.-C. ground potential, a potentiometer having a terminal connected to a common point with said end of said insulated resistance wire, a slider contacting said potentiometer, bridge means comparing the resistance of said insulated wire between said end and said point to the resistance of the portion of said potentiometer between said slider and said common point, and servo means for moving said slider in response to the unbalance of said bridge means to maintain said bridge means in balance whereby the resistance of said insulated wire between said end and said point is exactly proportional to the resistance of said potentiometer between said slider and said common point.

4. Apparatus for automatically winding a potentiometer of insulated resistance wire without piercing the insulation of said wire so as to be electrically similar to a master potentiometer comprising an elongated mandrel for carrying the wire of said potentiometer to be wound, means for rotating said mandrel at a constant speed, a spool for storing said wire to be wound on said mandrel, a carriage adapted to move only in the direction of the longitudinal axis of said mandrel, guide means carried on said carriage for paying said wire on said mandrel as said carriage moves, a conductive fluid bath, means for conveying said insulated resistance wire through said fluid bath immediately prior to paying said wire on said mandrel, a source of electric signals, means connecting said resistance wire and said master potentiometer in series across said source of electric signals, a slider attached to said carriage for contacting said master potentiometer, said master potentiometer being fixed in space, means utilizing the capacitance between said bath and said wire in said bath for producing a signal indicative of the departure of said wire in said bath from ground potential, electronic servo means responsive to said signal producing means and having its output connected to said series circuit in a manner to maintain the potential of said wire in said bath at ground potential, means responsive to the signal across said wound potentiometer and to the signal across said master potentiometer for producing an output proportional to the deviation of said signals from a predetermined ratio, and servo means for moving said carriage in response to the output of said signal deviation producing means whereby the resistance of the wire wound on said mandrel is maintained in a predetermined ratio with the resistance of said master potentiometer where said slider contacts it.

5. Apparatus for automatically winding an insulated resistance wire onto a potentiometer form without piercing the insulation of said wire so as to be electrically similar to a master potentiometer comprising means for holding said master potentiometer stationary in space, a rotatable mandrel for holding said potentiometer to be wound, support means for holding said mandrel stationary in space with its longitudinal axis parallel to the longitudinal axis of said master potentiometer, a motor for rotating said mandrel, a carriage movable in a direction parallel to the axes of said master potentiometer and said mandrel, means attached to said carriage for paying resistance wire onto said mandrel as it rotates, slider means attached to said carriage and contacting said master po-

tentiometer, a conductive fluid bath, means conveying said resistance wire through said conductive fluid bath at a point just prior to winding on said mandrel, means utilizing the capacitance between said conductive fluid bath and said resistance wire in said bath for producing a signal indicative of the departure of said wire in said bath from a predetermined potential, a source of electric signals, means connecting said resistance wire and said master potentiometer in series across said source of signals, electronic servo means responsive to said signal producing means for maintaining said wire in said bath at said predetermined potential, means for comparing the potential across said resistance wire wound on said mandrel with the potential picked off by said slider, and servo means responsive to said voltage comparison means for changing the axial spacing of said resistance wire being wound on said mandrel whereby the resistance of said wound potentiometer is in a predetermined ratio with the resistance of said master potentiometer.

6. In a potentiometer winder for winding insulated resistance wire on a mandrel to correspond electrically to a master potentiometer without piercing the insulation of said wire, the combination of a conductive fluid bath, means for conveying said resistance wire through said fluid bath at a point just prior to being wound on said mandrel, means utilizing the capacitance between said conductive fluid bath and the wire in said conductive fluid bath for determining the magnitude of the resistance of the wire wound on said mandrel, and means for varying the spacing of the turns of insulated wire on said mandrel in response to said resistance determining means.

7. Apparatus for automatically winding a potentiometer with insulated resistance wire so as to be precisely proportional to a master potentiometer without piercing the insulation of said wire comprising a rotatable mandrel restrained against longitudinal movement, means for paying resistance wire onto said mandrel as it rotates, a conductive fluid bath, means for conveying said resistance wire through said conductive fluid bath at the point where said wire is payed onto said mandrel, signal generating means, means connecting said resistance wire and said master potentiometer in series across said signal generating means, capacitive detector means utilizing the capacitance between said conductive fluid bath and said resistance wire in said conductive fluid bath for sensing the deviation of said resistance wire in said conductive fluid bath from a ground potential, electronic servo means sensitive to the output of said capacitive detector means and connected to adjust the potential applied across said series connection in a manner to maintain said wire in said bath at substantially ground potential, slider means associated with said paying means for contacting said master potentiometer, signal comparison means responsive to the potential at the common terminal between resistance wire and said master potentiometer and to the potential picked off by said slider means for generating an output signal which is a predetermined function of the deviation of said potentials from a predetermined ratio, and means for advancing said paying and slider means in response to the output of said signal generating means to thereby wind a potentiometer precisely proportional to said master potentiometer.

8. Apparatus for automatically winding insulated resistance wire on a potentiometer without piercing the insulation thereof in a manner to be the electrical analog of a master potentiometer comprising a mandel, means for winding said wire on said mandrel with controllable spacing, a conductive fluid bath, means for conveying said resistance wire through said conductive fluid bath immediately prior to winding on said mandrel, capacitive detector means utilizing the capacitance between said conductive fluid bath and said resistance wire in said conductive fluid bath sensitive to the deviation of said wire in said bath from a ground potential, a slider on said master potentiometer, means for advancing said slider in synchronism with the motion of said winding means along the axis of said mandrel, a source of electric signals, means connecting said resistance wire and said master potentiometer in series across said source of electric signals, electronic servo means responsive to said capacitive detector means for maintaining said wire in said conductive fluid bath at ground potential, a pair of fixed resistors bearing a predetermined ratio inter se which is a function of the ratio it is desired to establish between said master potentiometer and said potentiometer being wound, one of said resistors being connected between the other of said resistors and said slider, an inverting amplifier having its input connected to the junction between said wound potentiometer and said master potentiometer and its output connected to the other of said fixed resistors, and servo means with its input connected to the junction between said resistors and its output connected to drive said advancing means whereby if said junction is not at ground potential said slider is moved in a direction and of a magnitude to bring said junction to ground potential.

9. Apparatus for automatically winding unbroken insulated resistance wire on a potentiometer to be the electrical analog of a master potentiometer comprising a cylindrical mandrel, means for winding said insulated wire on said mandrel with controllable spacing, a conductive fluid bath through which said wire passes, capacitive means associated with said bath for producing a signal indicative of departure of the wire from ground potential, a slider on said master potentiometer, amplifier means having its output connected to said slider for correcting the potential of said slider so that said insulated wire is at ground potential where it passes through said bath, means for advancing said slider in synchronism with the motion of said winding means along the axis of said mandrel, a pair of fixed resistances bearing a predetermined ratio inter se which is a function of the ratio it is desired to establish between said master potentiometer and said potentiometer being wound, one of said resistances being connected between the other said resistance and said slider, an inverting amplifier having its input connected to the junction between said wound potentiometer and said master potentiometer and its output connected to the other of said resistances, means for supplying an alternating current signal to said master potentiometer and said wound potentiometer connected in series, and servo means responsive to the deviation of the junction between said fixed resistances from a ground potential for driving said advancing means whereby if the input to said inverting means is not equal to a predetermined ratio of the potential at said slider said slider is moved until the resistance of said wound potentiometer bears the same ratio to said master potentiometer as said resistance connected to said inverting amplifier bears to the sum of said fixed resistances, and the input to said inverting amplifier becomes exactly equal to a predetermined factor of the potential picked off by said slider.

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