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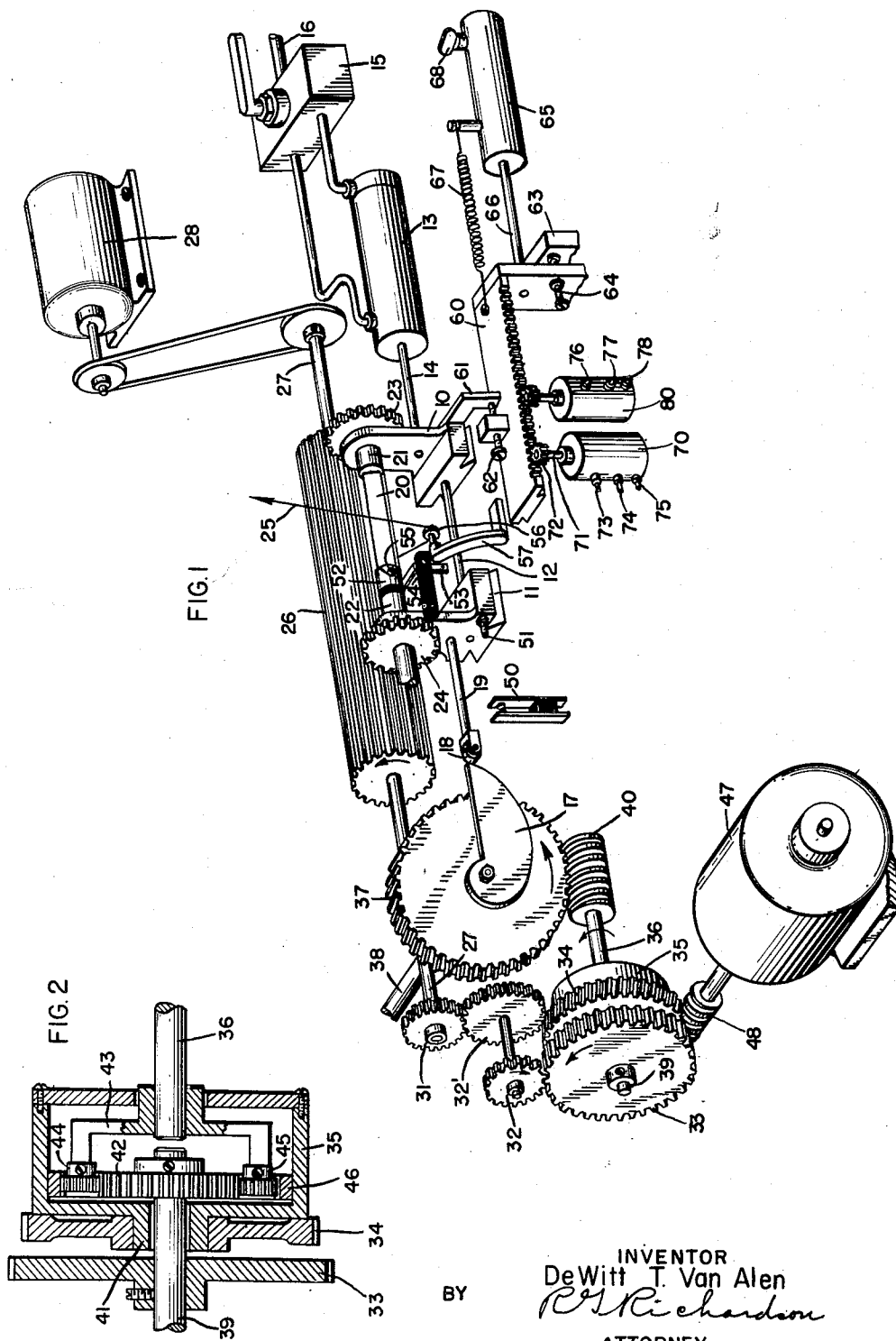
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COIL WINDING MACHINE

Filed Dec. 15, 1947

2 Sheets-Sheet 1



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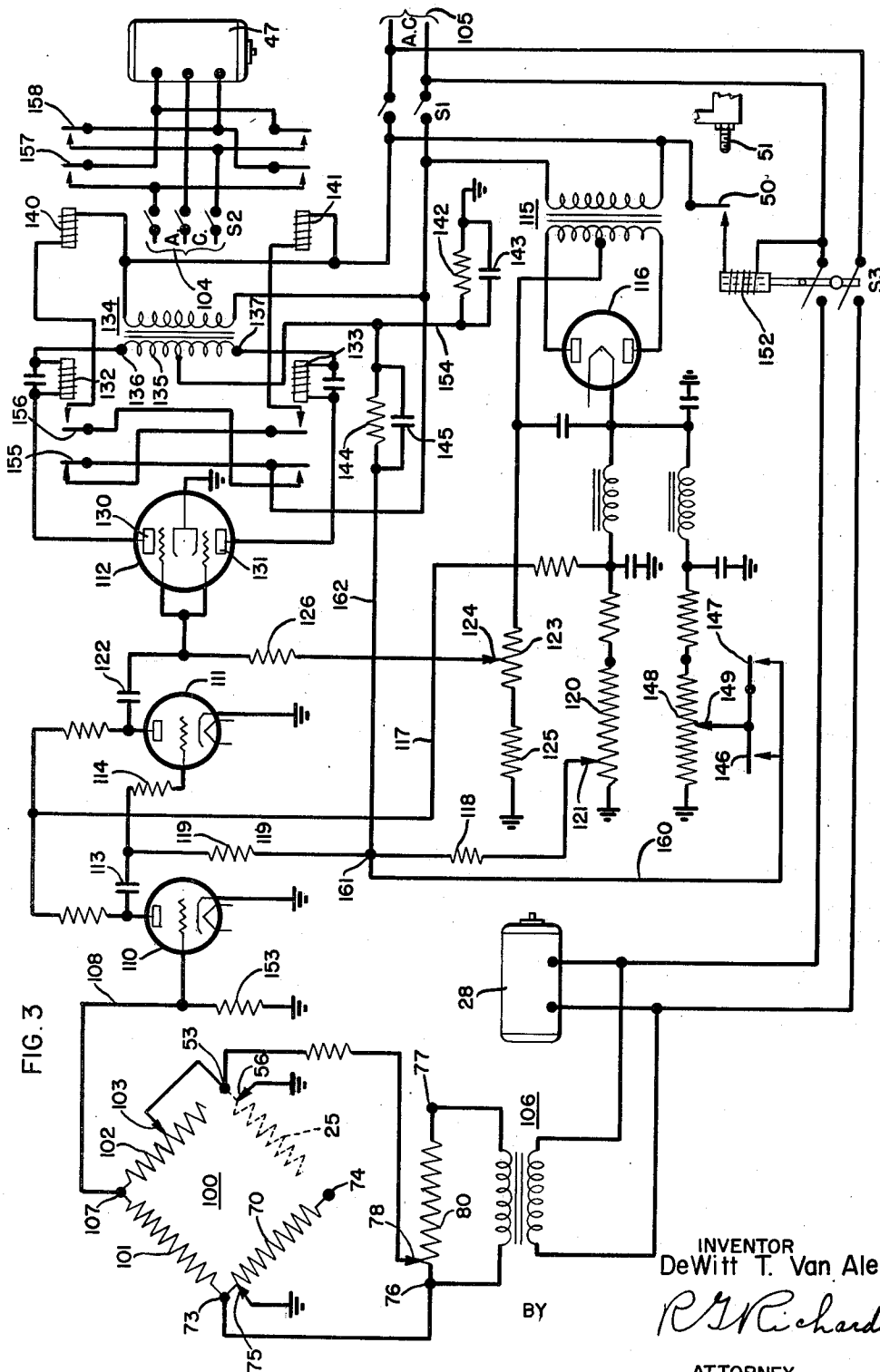
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UNITED STATES PATENT OFFICE

2,668,670

COIL WINDING MACHINE

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8 Claims. (Cl. 242—9)

1

The present invention relates in general to coil winding machines and more in particular to winding machines which are adapted to wind single layer coils of resistance wire on strips of insulating material in the manufacture of resistance elements for rheostats and potentiometers.

The invention is applied to a coil winding machine of the type disclosed in the application of Gilman et al., S. N. 563,522, filed November 15, 1944, now Patent 2,466,227. In making a resistance element on this machine the strip is rotated to wind the resistance wire thereon and is moved longitudinally to space the successive turns apart. The longitudinal movement of the strip is governed by a cam having a rise equal to the length of the winding space and connected by reduction gearing to the spindle which rotates the strip. Thus the number of turns of wire in a given length winding space can be accurately predetermined in accordance with the desired total resistance of the winding.

The calculation of the number of turns involves an assumption as to the resistance of the wire per unit length. The resistance is known or can be measured accurately but it is impracticable to measure the resistance of the wire for each resistance element. The value of the resistance is therefore taken as the average value obtained by measuring a number of samples. Due to slight variations in wire size, composition of the alloy, and other factors, it is found that resistance elements having the same number of turns and wound on strips of the same width and thickness (so far as can be made) will vary considerably in total resistance.

It is the object of the invention to overcome the foregoing difficulty and make possible the quantity production of resistance elements having the same total resistance notwithstanding variations in the resistance of the wire. The desired result is accomplished by automatically and continuously testing the resistance of the winding as it is formed and increasing the turn spacing if the resistance starts to increase too fast and decreasing the turn spacing if the resistance of the winding increases too slowly. Thus if the resistance of the wire is higher than the assumed value less turns are put on the strip while if the resistance of the wire is less than the assumed value more turns are put on.

A feature of the invention is a differential mechanism which effectively changes the gear ratio between the spacing cam and the spindle which rotates the strip. The differential mecha-

2

nism is controlled by the resistance testing means and increases or decreases the gear ratio as required.

The invention will be described more in detail in the ensuing specification, reference being had to the accompanying drawings, in which—

Fig. 1 is a diagrammatic representation of a coil winding machine modified in accordance with the invention;

Fig. 2 is a cross section through the differential mechanism; and

Fig. 3 is a diagrammatic circuit drawing showing the electrical equipment and connections thereof.

The coil winding machine shown in Fig. 1 includes a so-called head stock 10 and tail stock 11 which are connected by the rod 12 and are slidable in ways like the corresponding parts in a lathe. The sliding movement of the head stock and tail stock is brought about by means of compressed air. The cylinder 13 has a piston which is connected to the head stock 10 by the piston rod 14. Compressed air from the supply pipe 16 may be admitted to either end of the cylinder 13 by means of the valve 15, whereby the head stock and tail stock may be moved to the right or left as desired. These parts are shown in their extreme right hand position in the drawing. The limit of movement in this direction may be determined by a suitable stop or by the piston engaging the closed end of the cylinder. Movement of the head stock and tail stock to the left is controlled by the cam 17, having the cam follower 18 which is connected to the tail stock 11 by the rod 19.

The strip of insulating material 20, on which the wire 25 is to be wound to make a resistance element, is supported on the spindles 21 and 22 by means of suitable collets, details of which are not shown. The spindles are rotatably mounted on the head stock 10 and tail stock 11, respectively, and are adapted to be rotated by the spur gears 23 and 24 which mesh with the wide faced pinion 26. This pinion is mounted on the shaft 27 which is driven by the motor 28 by means of the belt and pulleys shown.

The shaft 27 also drives the cam 17 which with the gear 37 is mounted on the shaft 38. The driving connection between shaft 27 and shaft 38 comprises the gears 31, 32, 32', and 33, the latter of which is mounted on the shaft 39, the differential mechanism in housing 35, shaft 36, worm 40, and gear 37. The cam 17 rotates very slowly as compared to the spindles 21 and 22 and it will be understood therefore that the speed

reduction in the gear train is considerable. There may be a 100 to 1 reduction in the worm 40 gear 37 connection and a 3 to 1 reduction in the differential. The gears 31, 32, 32' and 33 are members of a set of interchangeable gears by means of which the speed ratio can be varied within wide limits.

The differential mechanism is shown in detail in Fig. 2. The input shaft is shaft 39 on which gear 33 is mounted. The output shaft is shaft 36 which carries the worm 40. The housing 35 has a central hub 41 by means of which it is rotatably mounted on the shaft 39. Inside the housing 35 there is a spur gear 42 fixed on shaft 39 and a spider 43 fixedly mounted on shaft 36. Supported on the spider 43 are a plurality of pinions such as 44 and 45 which mesh with gear 42 and also with the internally toothed gear 46 which is fixed to the inner wall of the housing.

The housing 35 is normally stationary but may be rotated in either direction by means of gear 34, worm 48, and the reversible motor 47. When the housing 35 and gears 34 and 46 are stationary shaft 39 drives shaft 36 at $\frac{1}{3}$ its own speed, that is, there is a 3 to 1 speed reduction as previously mentioned. When the gear 34, housing 35 and gear 46 are rotated in the same direction as the direction of rotation of shafts 39 and 36 the speed of the latter shaft relative to shaft 39 is increased, but when the gear 34, housing 35, and gear 46 are rotated in the opposite direction the speed of shaft 36 is decreased.

The reference character 50 indicates a switch which is actuated by an adjustable stud 51 carried on the front end of the tail stock 11 when the latter reaches the end of its movement to the left. It is the closure of this switch which stops the movement as will be explained subsequently.

The spindle 22 has an insulated sleeve or slip ring 52 near the end, which is engaged by the brush or wiper 53. The latter is mounted on the tail stock 11 by a suitable insulating bracket such as 54. The wire 25 is secured to the slip ring 52 in any suitable manner, by means of the small screw 55, for example. After passing around the strip 20 the wire passes around the pulley 56 and thence by way of the tensioning mechanism to the supply spool on which it is wound. The pulley 56 is made of conducting material and is mounted on a fixed part of the machine by the support 57. The pulley 56 thus affords means for grounding the wire substantially at the last turn on the strip. In practice it is grounded very nearly at the strip since there is an intervening guide wheel or pulley which guides the wire directly on to the strip, as shown in the Gilman et al. application previously referred to.

The reference character 60 indicates a rack which is slidably mounted like the head stock and tail stock. The rack is moved to the left by the member 61 mounted on the head stock 10 and adapted to engage the adjusting screw 62 mounted on the rack when the head stock moves to the left under control of the cam 17. This movement of the rack tensions the spring 67 which returns the rack to its right hand position, after the head stock has returned, under control of the dash pot 65. The dash pot contains a piston which is connected to the rack 60 by the piston rod 66 and has a valve 68 near the end for regulating the admission and ejection of air. The limit of the rack's movement to the right is determined by engagement of the adjusting screw 64 with the stop 63.

The reference character 70 indicates a potentiometer, which is preferably of the type disclosed in the pending application of Gibbs et al., S. N. 573,680, filed January 20, 1945. This potentiometer has a resistance element in the form of a ten turn compound helix connected between terminals 73 and 74 and a rotatable brush driven by the shaft 71 and connected through a slip ring arrangement to the terminal 75. The shaft 71 is rotated about 9 or $9\frac{1}{2}$ turns by the pinion 72 and rack 60 during the movement of the rack to the left. When the parts are in the position in which they are shown in the drawing the rotatable brush is in engagement with the resistance element at terminal 73 and the resistance between terminal 72 and terminal 75 is zero, or substantially zero. As the shaft 71 rotates, the brush travels along the resistance element and the resistance between terminals 73 and 75 increases, approaching the maximum resistance after 9 or $9\frac{1}{2}$ turns. Terminal 74 is not used.

The potentiometer 70 should be carefully selected so as to afford the best possible resistance curve, which should be linear or as near an approximation as can be made. The effect of such unavoidable departures from linearity as may be present are minimized by the great length of the resistance element, about 42 inches, requiring an angular movement of the brush of around 3240 degrees or more.

The potentiometer 80 is similar to potentiometer 70, but need not be so accurate as regards linearity of its resistance curve. The terminals of the resistance element are indicated at 76 and 77, while 78 is the terminal connected to the movable brush.

Referring now to Fig. 3, the motors 47 and 28 of Fig. 1 are shown and are indicated by the same reference numerals. Also the switch 50 and the actuating stud 51 on the tail stock.

The potentiometer 70 is included as one arm of the bridge circuit 100. The other arms are the resistance 101, the variable resistance or rheostat 102, and the resistance wire 25 of the resistance element which is wound on the machine. The potentiometer 70 may have a total resistance of about 10,000 ohms, resistance 101 may be 20,000 ohms, and the rheostat 102 may have a range up to 20,000 ohms. These values are suitable for winding resistance elements ranging from several thousand ohms up to about 10,000 ohms.

Current is supplied to the bridge circuit from the potentiometer 80 which is shunted across the secondary winding of the transformer 106. It is thought that the circuit connections of the bridge will be clear without detailed explanation. It may be pointed out, however, that the junction point 53 is the brush 53 of Fig. 1 which is conductively connected with the end of wire 25 during the winding of the resistance element. The slider 56 is the pulley 56 of Fig. 7, which is in conductive connection with the wire where it leaves the strip.

The control circuit including the tubes 110, 111, and 112 may now be described briefly.

The junction point 107 on the bridge circuit 100 is connected by a conductor 108 to the grid of the tube 110, which may be a type 6F5 tube and operates as an amplifier.

The plate circuit of tube 110 is connected by way of the condenser 113 and the resistance 114 to the grid of tube 111, which may be another type 6F5 tube. The tube 111 has a positive bias and functions as a positive half cycle eliminator.

A positive plate voltage is supplied to the tubes

5

110 and 111 over conductor 117 from the rectifier comprising the transformer 115 and the full wave rectifier tube 116. This rectifier also supplies the positive biasing voltage to the grid of tube 111 as will be explained briefly.

The biasing connection includes the potentiometer 120, having the slider 121, the resistance 118, and the resistance 119. The amount of positive bias is determined by the position of the slider 121, and should be sufficient to cause the grid to draw current. The amount of grid current which can flow is limited by the resistance 114. This resistance is preferably at least one-half megohm, and is high relative to the internal resistance between the cathode and grid in the tube, so that the major portion of the biasing voltage appears across the resistance 114 and only a small fraction of it between the grid and cathode. The effect is to give the tube a plate current curve which levels off sharply at the point where the grid becomes positive and starts to draw current. Positive half waves of signal voltages transmitted from the preceding stage via condenser 113 accordingly have very little effect on the plate current at tube 111. The negative half waves of such signal voltages, however, if strong enough to overcome the positive grid bias, cause large fluctuations in the plate current. The potentiometer 120 is used to control the sensitivity of the circuit. Decreasing the positive bias increases the sensitivity, that is, it makes the tube responsive to negative signal voltages of smaller amplitude, while increasing the positive bias decreases the sensitivity.

The plate circuit of tube 111 is coupled by means of the condenser 122 to the grids of the tube 112 which may be a type 6SN7 double triode. The grids of tube 112 have a negative bias, derived by way of resistance 126 from the biasing circuit which includes the potentiometer 123 and resistance 125, and the tube responds to positive impulses which are generated at tube 111 in response to negative signal impulses. The value of the negative bias is adjusted by means of slider 124 and should be sufficient to cause the tube to operate on an efficient part of its plate current curve.

The plate circuits of the tube 112 are supplied with current by the center tapped secondary winding 135 of the transformer 134. One plate circuit includes the cathode of the tube, the plate 130, relay 132, and the upper half of the secondary winding, and carries current at times when the junction point 136 is positive, provided there is a positive potential on the grid. The other plate circuit includes the cathode of the tube, the plate 131, relay 133, and the lower half of the secondary winding, and carries current at times when the junction point 137 is positive, if there is a positive potential on the grid. When junction 136 is positive, junction 137 is negative and vice versa, that is, the effective plate voltages applied to the plate 130 and 131 are 180 degrees out of phase with each other. When the circuit is functioning, the grids of the tube 112 receive only one positive impulse per cycle and these impulses are in phase with the positive potentials applied to the plate 130 or with the positive potentials applied to the plate 131, depending on the direction in which the bridge 100 is unbalanced, but cannot be in phase with both. Thus only one of the two relays 132 and 133 can energize under any given condition of unbalance.

It will be understood that the "in phase" rela-

6

tion between the positive potentials applied to the plate 130 or plate 131 of tube 112 and the positive impulses received at the grids of the tube in response to an unbalanced condition at the bridge 100 results from the fact that the transformers 106 and 134 are supplied with power from the same source of alternating current.

The relays 132 and 133 control the electromagnetic switches 140 and 141, respectively, which operate the motor 47.

The resistance 142, shunted by condenser 143, is common to both plate circuits of the tube 112 and provides a feed back voltage, as will be explained more fully later on.

The potentiometer 143, having adjustable slider 149, provides a positive potential, known as throttling voltage, which is applied to the grid of tube 111 whenever relay 132 or 133 energizes. The contacts 146 and 147, shown detached for convenience, are on the relays 132 and 133, respectively. The function of the throttling voltage will also be explained later on.

The bracket 104 indicates a source of three phase alternating current which supplies power for operating the motor 47 under control of the manually operable switch S2 and the electromagnetic switches 140 and 141.

The bracket 105 indicates a source of single phase alternating current which supplies power to other parts of the apparatus. A switch S1 connects the said source to the transformer 115, transformer 134, and to the circuits for the electromagnetic switches 140 and 141. Another switch S3 connects the source 105 to the motor 47 and to the transformer 106.

The operation of the machine may now be described. It may be assumed for this purpose that it is desired to wind resistance elements having a resistance of 5,000 ohms. Any other resistance within reasonable limits could be selected but this will serve as an example and afford an opportunity of explaining the procedure.

The length of the winding space on the strip such as 20 is known, also the width and thickness of the strips, which gives the length of each turn. With this information and standard wire tables, it is possible to determine the size of wire to be used and the number of turns which will be required in order to give a total resistance of 5,000 ohms. The number of turns required for the desired total resistance depends on the wire size, and the latter should be so selected that the corresponding number of turns will go into the winding space with a medium spacing which can be increased or decreased if necessary to correct for variations in wire resistance.

The number of turns having been determined, the gear ratio between the spindles 21 and 22 and the cam 17 can be calculated and the proper gears such as 31, 32, 32', and 33 can be installed. The gear ratio should be such that during the angular motion of the cam in winding a strip, about 340 degrees, the spindles make a number of rotations equal to the number of turns.

The cam 17 is a straight line cam and should have a rise equal to the length of the winding space.

With the apparatus in the position in which it is shown in Fig. 1, the adjusting screw 64 should be adjusted to set the potentiometer 70 to zero, that is, with the movable brush 75 at the terminal 73 end of the resistance element, as shown in Fig. 3. This will also adjust potentiometer 80 to zero, but if it does not, the necessary adjustment

7

is accomplished by rotating the potentiometer while the pinion is in engagement with the rack.

Compressed air may now be admitted to the right hand end of cylinder 13 by means of valve 15, thereby moving the headstock assembly and strip 20 to the left and causing the follower 18 to engage the cam 17. In this position of the parts the member 61 should engage the end of adjusting screw 62 without, however, bringing about any movement of the rack 60. The screw 62 should be adjusted, if necessary, to fulfill these conditions. The switch S3, Fig. 3, may now be closed to start the motor 28. The wire 25 has not yet been attached to the slip ring 52. Motor 28 rotates the spindles 21 and 22 and the cam 17 and is allowed to run until the cam has rotated the amount it is required to rotate in winding a strip, assumed to be 340 degrees. The motor is then stopped by opening the switch S3. The headstock assembly is now in its extreme left hand position and the stud 51 is adjusted so that it will operate the switch 50 at this point. This provides for automatically opening the switch S3 by means of solenoid 152 during actual winding operations.

The movement of the headstock assembly to the left causes a corresponding movement of the rack 60, whereby the shaft 71 of the potentiometer 70 is rotated about 9 or $9\frac{1}{2}$ turns. The amount of rotation is not critical but should be sufficient to utilize the major portion of the resistance element. The movable brush 75 of the potentiometer will therefore be near the terminal 74 end of the resistance element. The shaft of potentiometer 80 is rotated at the same time as shaft 71 and accordingly the movable brush 78 will be near the terminal 77 end of the resistance element.

The next operation is to adjust the bridge 100 for winding 5,000 ohm resistance elements. This is done by connecting an accurate 5,000 ohm resistance in the strip arm of the bridge and then adjusting the rheostat 102 in the adjacent arm until the bridge is in balance. The known resistance may be a standard decade resistance box, adjusted to 5,000 ohms, and may be connected between the terminal 53 and ground or between the terminal 53 and the grounded terminal 75 of potentiometer 70. An unbalanced condition may be detected in any suitable manner, as by connecting an A. C. voltmeter between the grounded terminal 75 and the junction 107 on the bridge. When the bridge is balanced there will be no difference of potential between these points. The adjustment of rheostat 102 having been completed the rheostat is left in adjusted position and the known 5,000 ohm resistance is removed from the strip arm of the bridge.

The operator may now shift the valve 15 so as to admit compressed air to the left hand end of cylinder 13, which incidentally opens the other end to the atmosphere. The headstock assembly is thus moved rapidly to its extreme right hand position, the position in which it is shown in Fig. 1. The rack 60 is moved to the right also under the influence of spring 67 but at a slower speed because of the dash pot 65. The potentiometers 70 and 80 are thus reset to zero resistance.

The switch S3 may now be closed for a long enough interval to advance the cam 17 to its starting position. This is the position in which the cam is shown in Fig. 1. The valve 15 is then reversed so as to admit air to the right hand end of cylinder B and place the headstock assembly under the control of the cam 17.

8

The machine is now ready to proceed with winding operations and the switches S1 and S2 can be closed so as to supply current to the control circuits.

It has been assumed that the strip 20 has previously been placed in the machine. The wire 25 is carried on a supply spool the rotation of which for delivering wire to the strip during winding thereof is controlled by tensioning apparatus. This apparatus is not shown herein since it is no part of the invention but is shown and described in the previously referred to application of Gilman et al. It will suffice to say here that the operator proceeds by taking the end of the wire from the spool and threading it through the tensioning apparatus, after which the wire is passed around the pulley 56 and the strip 20 and the end is secured to the slip ring 52 by the screw 55.

The operator may now close the switch S3 to again complete the circuit of motor 28. The motor rotates the spindles 21 and 22 and the strip 20 supported thereon, and accordingly the wire 25 is wound on the strip in spaced turns, the cam 17 being rotated slowly at the same time in order to space successive turns apart. The spacing at the start is in accordance with the calculated number of turns required to give the desired resistance of 5,000 ohms.

As the winding operation proceeds, the shafts of the potentiometers 70 and 80 are rotated by the rack 60. The brush 78 of potentiometer 80 is therefore moved away from terminal 76 and toward terminal 77 to gradually increase the voltage applied to the bridge circuit 100, and thereby maintain its sensitivity substantially constant. The brush 75 of potentiometer 70 is moved away from terminal 73 and toward terminal 74 and the resistance of the potentiometer arm of the bridge, which is zero at the start, is gradually increased. At the same time the pulley 56 maintains a ground connection to the wire 25 where it leaves the strip 20 and accordingly the resistance of the strip arm of the bridge, also zero at the start, is gradually increased. If the increase in the resistance of the strip arm is in accordance with the previous calculations it will be proportionate to the increase in the resistance of the potentiometer arm and the bridge 100 will remain in balance.

It may be assumed now that the wire 25 is somewhat oversize and therefore has less resistance per turn than it should have. In accordance with this assumption, the resistance of the strip arm will increase too slowly in proportion to the increase in the resistance of the potentiometer arm and the bridge will become unbalanced.

The unbalanced condition of the bridge results in an alternating potential between ground and the junction 107 on the bridge and an alternating current flow is established which produces a drop across the resistance 153. The alternating voltages thus developed are applied to the grid cathode circuit of tube 110 where they are amplified in the usual manner.

The output of tube 110 is alternating in character and is transmitted to the grid circuit of the control tube 111 by way of condenser 113. Due to the positive bias on the grid of this tube the positive half waves of signal current have no effect, as previously explained, but the negative half waves produce drops in the plate current through the tube as soon as they become strong enough to overcome the small positive bias. The resulting positive impulses produced at the plate of the

tube are transmitted by way of the condenser 122 to the grids of tube 112.

The positive impulses received at the grids of tube 112 are in phase with the positive potentials which are applied to plate 130 of the tube by the transformer 134 and are 180 degrees out of phase with the positive potentials applied to plate 131. Hence no current can flow in the circuit of plate 131 and relay 132. Relay 132 is energized, however, over a circuit which may be traced from the center tap of winding 135, by way of conductor 154, resistance 142, ground, cathode of tube 112, plate 130, relay 132, and the upper half of winding 135 back to the center tap of the winding. Current flow in this circuit develops a pulsating negative D. C. voltage on conductor 154, due to the drop across resistance 142, which is fed back by way of resistance 144 to the grid of tube 111, thereby reinforcing the negative half waves of the signal voltage. These feed back impulses insure positive energization of relay 132. The condenser bridged around the relay is charged each time current flows in the relay circuit, that is, during each half cycle when junction 133 is positive, and discharges through the relay during the intervening half cycles, thereby maintaining the relay energized in spite of the intermittent current flow in the rest of the circuit.

Upon energizing, relay 132 opens a point in the circuit of electromagnetic switch 141 at contact 155, and at contact 156 closes the circuit of electromagnetic switch 140, which energizes and at contacts 157 and 158 completes circuits from the three phase power supply source 104 to the motor 47. The motor 47 now starts up and rotates the gear 34 of the differential mechanism in the proper direction to decrease the speed of shaft 36 and the speed of cam 17 driven thereby. The effect of this is to decrease the turn spacing, or increase the ratio of turns to unit movement of the cam, which amounts to the same thing. Thus the operation of motor 47 begins to correct for the low resistance of the wire 25.

Returning now to relay 132, when this relay energizes, it closes its contact 146 and thus applies a positive throttling voltage from the potentiometer 148 to the grid circuit of tube 111 by way of conductor 160, which connects to the grid circuit at junction 161. The positive throttling voltage is high enough to cancel the negative feed back impulses transmitted over the conductor 162 in the feed back circuit and maintain the positive bias on the grid of tube 111 at a value which is somewhat higher or more positive than the bias derived from the sensitivity control potentiometer 120. This gives the relay 132 a chance to de-energize as soon as the correction initiated by starting motor 47 has proceeded far enough to substantially reduce the strength of the output impulses from the control tube. This action takes place very fast and the relay may restore almost immediately.

The restoration of relay 132 stops the motor 47 and opens contact 146, thereby cutting off the throttling voltage from the grid circuit of tube 111. The high positive bias on the grid does not return to its normal low value at once, however, due to the fact that condenser 145 has become charged and maintains the grid bias higher than normal for a period of a few cycles as it discharges through the resistance 144.

As the positive bias returns to its normal value the sensitivity of the tube 111 increases and if the bridge is still unbalanced the negative half waves of signal voltage will again produce drops

in plate current, whereby positive impulses are again transmitted to the grids of tube 112 to operate relay 132 and start the motor 47. The previously described operations are thus repeated.

The operation from here on depends on the resistance of the wire 25 being wound on the strip. If the resistance of the remainder of the wire is normal a few correcting operations will bring the bridge in balance. If the wire is uniformly of too low resistance throughout its length, however, the bridge will continually become unbalanced and the correcting operations will be repeated throughout the winding of the strip.

When the winding is completed, the stud 51 closes switch 50, thereby energizing solenoid 52 to open switch S3 and stop the machine. The wire is now cut off and the ends of the winding may be secured in place by tape, pending the application of permanent terminals. Screw 55 is then loosened, the wire is disconnected from the slip ring 52, and the wound strip is removed from the machine. Another strip may now be inserted and wound in the same way as described.

In the course of further winding operations a spool of wire may be encountered which has too high a resistance. When a strip is wound with this high resistance wire the bridge will become unbalanced shortly after the winding starts but in this case it will become unbalanced in the opposite direction and the output current from the bridge will be 180 degrees out of phase with the output current which resulted from the former condition of unbalance. The positive impulses transmitted from the control tube 111 to the grids of tube 112 will therefore be in phase with the positive potentials applied to plate 131 and relay 133 will be energized. Relay 133 operates the electro-magnetic switch 141 which closes circuits for motor 47 as shown, which now reverses its former direction of rotation and rotates the gear 34 of the differential mechanism in the proper direction to increase the speed of shaft 36 and cam 17. Thus the turn spacing is increased and the number of turns is decreased to compensate for the higher resistance of the wire. The correcting operations are otherwise the same as described and need not be gone over again.

In case a question should arise as to why a condition of unbalance resulting from too low wire resistance operates relay 132 rather than relay 133, or why the opposite condition of unbalance operates relay 133 rather than relay 132, it may be stated that the proper phase relationship depends on the primary windings of the transformers 106 and 134 being correctly connected to the line. When the machine is first set up and tested, if it is found that the motor 47 runs in the wrong direction in response to an unbalanced condition of the bridge, the trouble may be corrected by reversing the connections to one of the primary windings.

While the invention has been described in connection with the winding of a linear resistance element, it should be pointed out that it is also applicable to the winding of non-linear resistance elements. It is well adapted, for example, to the winding of non-linear resistance elements such as disclosed in my pending application Serial No. 602,813, filed July 2, 1945, in which uniform diameter wire is used and a variable spacing is employed to give the desired non-linear characteristic to the resistance curve. Tapered wire may also be used to give the desired resistance curve, either alone or in combination with a variable spacing. In any case the potentiometer 70 should

have a resistance curve which is the same as the resistance curve of the resistance element to be wound.

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

I claim:

1. In a coil winding machine, means for rotating a strip of insulating material to wind a resistance wire thereon, means for moving said strip longitudinally to space the turns of the winding a predetermined distance apart, means for comparing the rate at which the resistance of the winding increases during the winding operation with a standard rate, means controlled by said comparing means for automatically changing the spacing if the rate at which the resistance of the winding increases is too fast or too slow said means for changing the spacing including gearing between the respective means for rotating and for moving the strip, and said gearing including a differential mechanism provided with separate motor means connected to and controlled by said comparing means.

2. In a coil winding machine, means for rotating a support to wind a resistance wire thereon, means geared to said rotating means for moving said support longitudinally at a predetermined rate to space the turns of the winding, means for testing the resistance of the winding as the winding operation proceeds, and means controlled by said testing means for automatically changing the gear ratio between said rotating means and said moving means if the resistance of said winding becomes too high or too low, said means controlled by the testing means including for the gear connections a differential provided with separate motor means responsive to said testing means.

3. In a coil winding machine, means mounted for progressive movement for winding a wire on a support to form a resistance element, means including a bridge circuit for testing the resistance of said winding as the winding operation proceeds, said bridge circuit having two bridge arms of which one arm is said winding and the other arm is a resistance which increases during the winding operation, means for supplying operating current to said bridge circuit, and means connected with the means for winding the wire automatically in response to the progressive movement to increase the voltage of said current in proportion to the increase in the resistance of said arms.

4. In a coil winding machine, means including an electrically controlled motor for correcting the rate for winding a wire on a support to form a resistance element, means including a bridge circuit for testing the resistance of said element as the winding thereof proceeds, said bridge circuit having two bridge arms of which one is the said element and the other is a rheostat having a movable contact, means for supplying operating current to said bridge, said last means including a current regulating device having a movable contact, and means operative during the winding of said element to rotate the movable contact of said rheostat in the proper direction to increase its effective resistance and to simultaneously rotate the movable contact of said regulating device in the proper direction to compensate for the increasing resistance of said arms, the regulated current being connected for the control of said motor.

5. In a coil winding machine, means for supporting a strip of insulating material, said means including a rotatable and endwise movable spindle, a source of power for rotating said spindle to thereby rotate said strip and wind a resistance wire thereon, means including a device geared to said spindle operative to move said spindle and strip longitudinally to space the turns of the winding, a rheostat having a movable contact, means operative to advance said movable contact responsive to the longitudinal movement of said spindle, a bridge circuit in which said winding and said rheostat form two opposite arms, a differential mechanism having a reversible motor for the control of the output thereof and included in the gearing between said device and said spindle, and means responsive to an unbalanced condition of said bridge circuit and dependent on the direction in which the bridge circuit is unbalanced to operate the motor of said differential mechanism to increase or decrease the rate of longitudinal movement of said strip relative to its rate of rotation.

6. In a coil winding machine, means for holding and rotating a strip adapted to form a support for a coil, means for feeding wire to said strip at a fixed point to form a coil on said strip responsive to its rotation, means for progressively advancing said holding and rotating means to move said strip past said fixed point to space the turns of the coil, a connection between said rotating means and said advancing means including suitable gears and a differential mechanism having a separate motor for the control of the output thereof, a rheostat having a rotatable contact, means responsive to operation of said advancing means to rotate said contact, a bridge circuit in which said coil and said rheostat form two opposite arms, a source of alternating current included in said bridge circuit and operative to produce an alternating output voltage when the bridge is unbalanced, and means controlled by said output voltage to operate said separate motor of said differential mechanism to regulate the speed of said advancing means and thereby cause the increase in the resistance of said coil to be proportionate to the increase in the resistance of said rheostat.

7. In a coil winding machine, means for winding a resistance wire on a support, including means for feeding the wire to the support, advancing means for producing relative movement between said support and feeding means to space the turns of the winding, means for continuously testing the resistance of the winding as the winding operation proceeds, said last means including a bridge circuit in which said winding and a correspondingly varying portion of a standard resistance form two opposite bridge arms, respectively, a source of alternating current included in said circuit and operative to produce an alternating output voltage when the bridge is unbalanced, means for amplifying said voltage and for eliminating alternate half waves to produce a signal comprising successive positive pulses which are in phase with the positive or negative half waves from said source depending on whether the resistance of the winding is too high or too low relative to the standard resistance, two space discharge devices having grids to which said signal is applied simultaneously, plate circuits for said devices supplied with operating voltages responsive to the positive and negative half waves from said source, respectively, two relays in said plate circuits, respectively, one or the other of which

13

is energized depending on the phase of the signal pulses, and means responsive to the energization of either of said relays to change the speed of said advancing means relative to that of said winding means, the energization of one relay being effective to increase the speed while the energization of the other relay is effective to decrease the speed.

8. In a coil winding machine, means for winding a resistance wire on a support, including means for feeding the wire to the support, advancing means for producing relative movement between said support and feeding means to space the turns of the winding, means for continuously testing the resistance of the winding as the winding operation proceeds, said last means including a bridge circuit in which said winding and a correspondingly varying portion of a standard resistance form two opposite bridge arms, respectively, means comprising suitable gears and a differential mechanism connecting said winding means and said advancing means, a reversible motor for operating said differential mechanism to speed up or slow down said ad-

14

vancing means relative to said winding means, depending on the direction of operation, a circuit for running said motor in each direction, two relays for closing said circuits, respectively, two space discharge devices having anode circuits including said relays, respectively, and sources of alternating anode voltage 180 degrees apart in phase, and means including said bridge circuit operating to transmit positive pulses to the grids of said devices which are in phase with the anode voltage at one device in case the resistance of the winding increases too slowly and in phase with the anode voltage at the other device in case it increases too fast.

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