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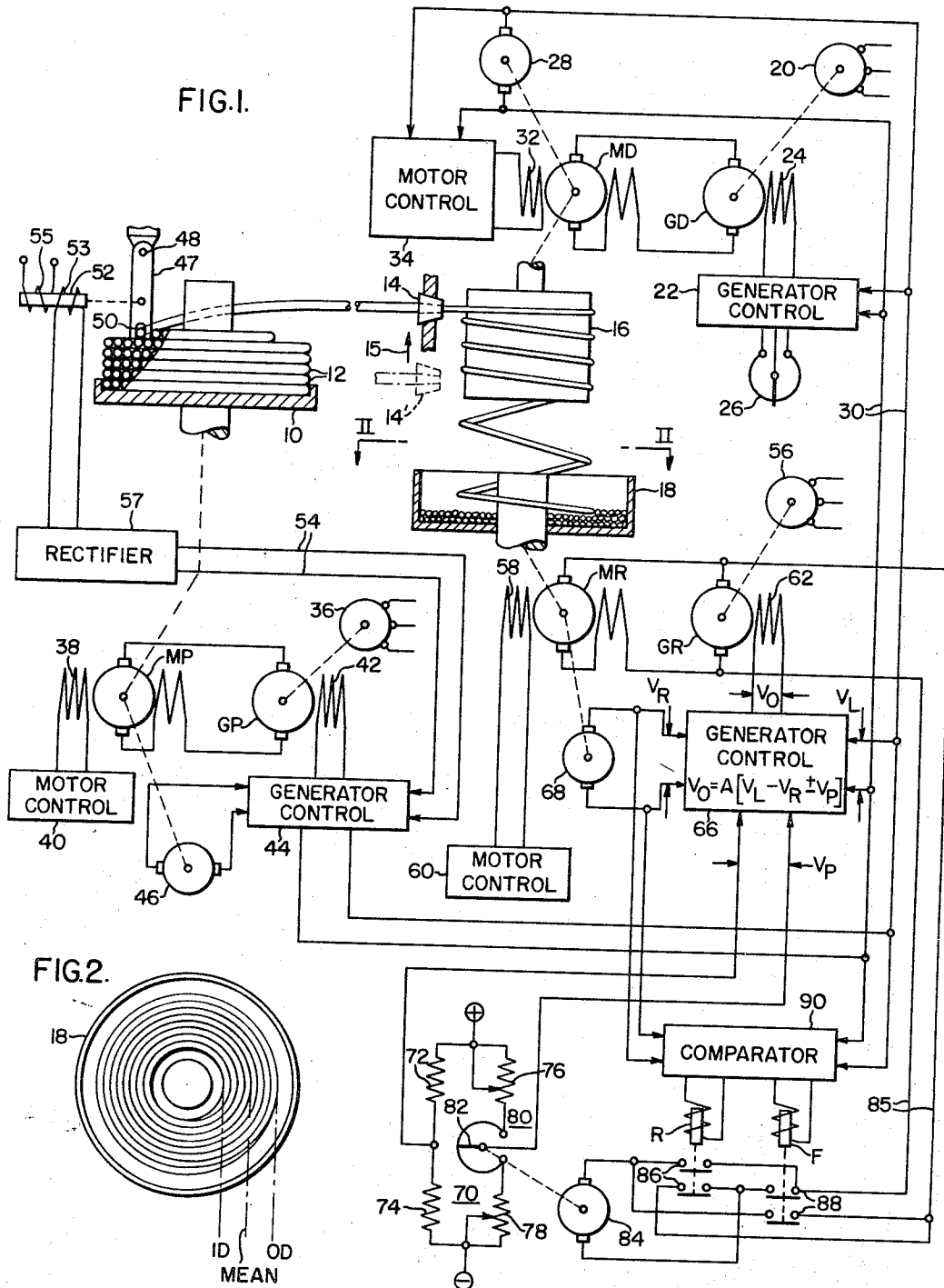
F. J. SMITH, JR., ETAL

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MOTOR CONTROL SYSTEM FOR COILING APPARATUS

Filed Feb. 16, 1966

2 Sheets-Sheet 1



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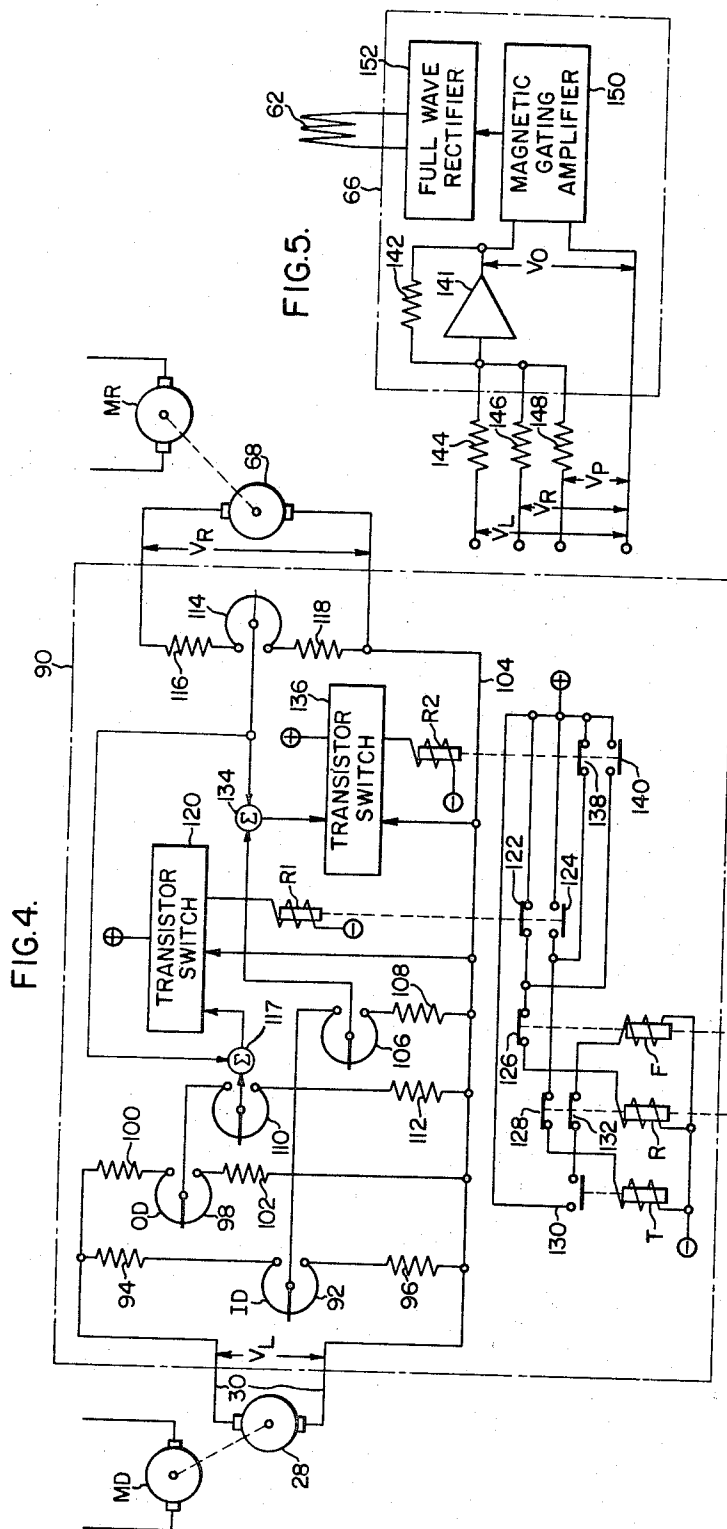
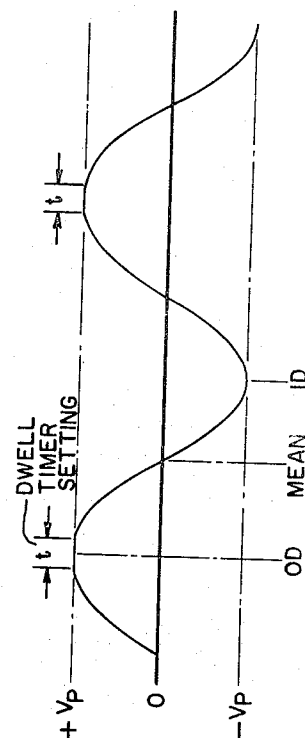
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MOTOR CONTROL SYSTEM FOR COILING

APPARATUS

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ABSTRACT OF THE DISCLOSURE

Tubing from a motor driven pay-off reel is drawn through a reducing die by a motor driven drawing drum on a vertical axis, around which drum several turns of the tubing are wound. The pay-off reel is speed regulated in accordance with the speed of the drum and further compensated by diameter change of stock on the reel. Processed tubing from the free lower end of the drum drops into a motor driven receptacle coaxial with the drum. The processed tubing is wound by the receptacle in successive pancake spiral layers by continuously undulating the receptacle speed from one to the other of maximum and minimum speeds. This is effected by apparatus which develops a receptacle speed control signal by summing a somewhat sinusoidally varying first control signal with second and third signals proportional to drum and receptacle speeds. The slope of the first control signal is periodically reversed at extrema of the signal by switches controlled in response to predetermined differences between the drum and receptacle speed signals.

The present invention relates to apparatus for continuously coiling tubular and the like stock in a rotating receptacle, and more particularly to apparatus of the type described for coiling the stock in even spiral layers.

While not limited thereto, the present invention is particularly adapted for use in apparatus for drawing metal tubing through a die by means of a rotating cylinder or drawing drum around which the drawn tubing is wrapped. In such apparatus, the tubing is pulled through the drawing die by the drum as it rotates about a vertical axis. As the drum rotates successive turns of drawn tubing will force the previously drawn turns of tubing to move downwardly until they reach the lower edge of the drum where they are permitted to fall into a rotating receptacle beneath the drawing drum. The advantage of the foregoing method is that it permits very long lengths of tubing to be drawn and coiled in contrast to a drawbench, for example, where the length of the tubing, drawn along a straight-line path of travel, is limited by the length of the drawbench bed.

One of the most serious difficulties encountered in drawing tubing on a rotating block is uneven coiling of the drawn stock in a rotating receptacle as it is discharged from the bottom of the drawing drum. If the tubing is permitted to simply fall into the rotating receptacle, it will often become entangled when it is uncoiled from the receptacle for further processing. This is a particularly acute problem in the case of small diameter thin-walled tubing where the tubing may break because of the entanglement.

As an overall object, the present invention seeks to provide an electrical control system for laying a continuous flat coil in a rotating receptacle in single or multiple layers of coil.

Another object of the invention is to provide apparatus for coiling newly drawn tubing, discharged from a drawing drum, in a rotating receptacle such that the tubing is wound in even spiral layers. As will be seen, this permits

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nearly trouble-free uncoiling of the spiral tubing for further processing or expenditure.

Still another object of the invention is to provide apparatus of the type described for coiling tubing, drawn by means of a rotating drum, in a rotating receptacle by comparison of an electrical signal proportional to the speed of the drum with an electrical signal proportional to the speed of the receptacle. In this respect, it will be appreciated that when the speed of the receptacle is decreasing with respect to that of the drum in an arrangement of the type described above, the spiral coil diameter is increasing; and as the speed of the receptacle increases with respect to that of the drum, the coil diameter decreases. Stated in other words, the coil diameter in the spiral depends upon the amount of tubing discharged from the drum into the receptacle during a single revolution of the receptacle. A comparison of the speeds, therefore, gives an accurate indication of coil diameter; and assuming that the speed of the drum is relatively constant, a back and forth spiral pattern of the discharged tube into multiple even layers can be achieved by increasing the speed of the receptacle (decreasing spiral diameter) to an upper limit followed by decreasing the speed of the receptacle from its upper limit to a lower limit (increasing spiral diameter), in which process two spiral layers of coil have been laid.

In accordance with the invention, the inner and outer diameters of the coil are determined by voltage responsive relay devices. One of these relays is tripped to decrease receptacle speed relative to drawing drum speed when the voltage proportional to the drum speed is normally below that proportional to receptacle speed by an amount determined by the operator. At this point, the stock entering the receptacle is at the minimum coil diameter. The other of the relays is tripped, preferably after a time delay, to increase receptacle speed relative to the drawing drum speed when the voltage proportional to the drum speed is above that proportional to receptacle speed by another amount determined by the operator. As will be seen, the time delay at the outer diameter is provided to permit the spirally-wound stock to "tighten" before the inward excursion begins.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIGURE 1 is a schematic circuit diagram of the control system of the invention;

FIG. 2 is taken substantially along line II—II of FIG. 1 showing a top view of the coil as wound in a rotating receptacle;

FIG. 3 is a graph illustrating the variation in speed of the rotating receptacle to achieve a spirally-wound coil;

FIG. 4 is a detailed circuit diagram of the voltage comparison apparatus used in the circuit of FIG. 1; and

FIG. 5 is a schematic diagram of the generator control circuit for the receptacle drive generator shown in FIG. 1.

With reference now to the drawings, and particularly to FIG. 1, the apparatus shown includes a payoff reel or table 10 which supports a coil of stock 12 to be drawn. To initiate a drawing operation, a reduced diameter end of the stock 12 is passed through a drawing die 14 and engaged by jaws, not shown, carried on a large cylindrical drum or "block" 16 which rotates about a vertical axis. As the drum is forcibly rotated about its vertical axis in a manner hereinafter described, it serves to pull the stock 12 through the drawing die 14 while causing it to wrap around the outer peripheral surface of the drum 16. In this process, the tube is reduced in diameter while its

length is increased, the inner diameter of the tube being controlled by a floating mandrel, not shown, during the drawing operation. The aforesaid jaws which grip the end of the stock 12 are carried at the lower edge of drum 16. At the beginning of a drawing operation, the die 14 is also at the lower edge of the drum as illustrated by dotted outline identified by the numeral 14'. However, as the drum 16 is initially caused to rotate, the die is caused to move upwardly along the direction of arrow 15 by any suitable means, not shown. In this process, successive turns of tubing are caused to wrap around the drum in the manner illustrated until the die 14 reaches its upper extremity shown in full lines. At this point, the forward end of the tubing is severed from the jaws at the lower edge of the drum. Upon continued rotation of the drum after severance, successive turns of tubing force the previously drawn turns downwardly along the periphery of the drum until they reach its lower edge where they fall into a rotating receptacle 18 beneath the drum 16.

As shown, the payoff table 10 is driven by means of a direct current motor MP; the drum 16 is forcibly rotated by means of a direct current motor MD; and the receptacle 18 is driven by means of a direct current motor MR.

The drive motor MD for the drum 16 is supplied with driving potential by means of a direct current generator GD driven by means of a three-phase alternating current motor 20 or the like. The output of the generator GD and the speed of the motor MD, is regulated by means of a generator control circuit 22 which supplies energizing potential to the field winding 24 for the generator. The speed of the drum 16, and, hence, the overall line speed is controlled by means of a manually operated rheostat 26 connected to the generator control circuit 22 as shown. The drive motor MD is mechanically connected as shown to a tachometer generator 28 which, through leads 30, supplies a feedback signal to the generator control circuit 22. Thus, the feedback from the tachometer generator 28 completes a servo loop where, for example, the speed of the motor MD will increase in response to a change in the position of the movable tap on rheostat 26 until the feedback signal on leads 30 cancels or balances that from the rheostat 26, at which point the speed of motor MD remains fixed. The direct current drive motor MD is also provided with an external field winding 32 in accordance with usual practice, the winding 32 being connected to a motor control circuit 34. The control circuit 34 is of the current control type and is regulated by means of the feedback signal from tachometer 28 on leads 30, this arrangement being used to control the speed of motor MD in the constant horsepower range.

The payoff table or reel 10 is driven by the direct current motor MP supplied with energizing potential by means of a direct current generator GP driven by a three-phase alternating current motor 36. Motor MP is provided with an external field winding 38 controlled by motor control circuit 40 comprising a conventional constant potential regulator. The field winding 42 for generator GP is controlled by means of generator control circuit 44, the primary control signal for which is that on leads 30 from tachometer 28. Should the speed of the drive motor MD for drum 16 increase or decrease, the signal on leads 30 from tachometer generator 28 will vary correspondingly, causing the speed of motor MP and table 10 to increase or decrease also, as the case may be. As the speed of motor MP increases in response to an increase in the speed of motor MD, the output voltage of tachometer generator 46 connected to the motor MP will increase also until the signal on leads 30 is balanced by that from the tachometer generator 46, whereupon the speed of motor MP will again be constant. Here, again, a feedback servo system is provided as was the case with the circuit arrangement for motor MD.

It will be appreciated that the speed of the payoff table 10 should vary as the diameter of the coil 12 unwound

thereon increases or decreases, as the case may be. Thus, as the coil diameter is decreasing, and assuming that the speed of drum 16 is constant, the speed of table 10 should increase. Conversely, as the coil diameter of coil 12 increases, the speed of the payoff table 10 should decrease. For this purpose, an arm 47 associated with the payoff table 10 is pivoted as at 48 and has a slot or opening 50 at its lower extremity which fits over the stock 12 as it issues from the table 10 in traveling to the die 14. Consequently, as the coil diameter decreases, the arm 47 will rotate in a counterclockwise direction; whereas an increase in coil diameter will cause it to rotate in a clockwise direction. The arm 47, in turn, is connected to a plunger 52 of magnetically permeable material within a coil 53 such that the signal on leads 54 fed back to the generator control circuit 44 will vary the speed of motor MP and that of table 10 as a function of the diameter of the coil being fed to the die 14. Magnetic flux is induced in the plunger 52 by means of coil 55 energized by a source of alternating current potential, not shown; while the output of coil 53 is rectified in rectifier 57 before being fed to circuit 44 where it modifies the reference signal on leads 30, depending upon the instantaneous diameter of the stock being fed to die 14.

With reference to motor MR, it is energized by means of a direct current generator GR driven by a three-phase alternating current motor 56. The motor MR is provided with an external field winding 58 connected to a motor control circuit 60 comprising a constant potential regulator. The field winding 62 for generator GR is connected to a generator control circuit 66 having three signals applied thereto and identified as V_R , V_P and V_L . The signal V_L comprises that on leads 30 and is, of course, proportional to the speed of motor MD and drum 16. The signal V_R is derived from a tachometer generator 68 mechanically coupled to the motor MR. Hence, the signal V_R is proportional to the speed of motor MR and the rotating receptacle 18. The third signal V_P is derived from a motor driven potentiometer arrangement 70 comprising two parallel current paths connected between the output terminals of a source of direct current potential, not shown. One parallel current path includes two fixed resistors 72 and 74 of equal resistance value. The other parallel current path includes manually adjustable variable resistors or pots 76 and 78, together with a rheostat 80 having its movable tap 82 mechanically connected to a direct current drive motor 84. As the coil diameter within receptacle 18 increases, the motor 84 will cause the movable tap 82 on rheostat 80 to rotate in one direction until the outer diameter of the coil is reached, at which point the motor 84 will be reversed to cause the tap 82 to rotate in the opposite direction.

The voltage V_P , when plotted with respect to time, will appear as in FIG. 3 and combines a cyclical, somewhat sinusoidal wave shape in which the voltage V_P increases from zero in a positive direction to an upper limit, then decreases back to zero and continues in the negative direction to a maximum negative limit; whereupon it again increases back to zero to complete a cycle. In this cycle, it will be appreciated that the tap 82, starting at its mid position for zero voltage, first rotates in a clockwise direction to the upper positive limit, then reverses and rotates in a counterclockwise direction through its mid position and thence to its maximum negative position; whereupon the motor 84 reverses and again drives the tap 82 in a clockwise direction. When the voltage V_P is at its minimum negative value, the coil diameter is at a minimum (i.e., ID shown in FIG. 2). From this point, it gradually increases in a positive direction through the mean diameter position (i.e., $V_P=0$) to its outer diameter position. When the outer diameter, OD, is reached, the motor 84 and, hence, the tap 82 dwell for a time period t shown in FIG. 3. During this period of time, the speed of the rotating receptacle 18 is neither increasing nor decreasing with respect to that of the drum 16. This main-

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tains the diameter of the coil in receptacle 18 substantially constant for the time delay t , thereby enabling the spiral coil configuration to "tighten up" before it begins its inward excursion to the inner diameter, ID.

The drive motor 84 for the movable tap 82 is driven from the output of generator GR on leads 85. The direction of rotation of motor 84, in turn, is controlled by two relays R and F. When the coil diameter is increasing, for example, the relay R will be energized to close its contacts 86, thereby causing motor 84 to rotate in one direction. On the other hand, when the coil diameter is decreasing, the relay F will be energized to close its contacts 88, whereupon the motor 84 rotates in the opposite direction. Since the motor 84 is driven by the output potential of generator GR, the speed of rotation of the tap 82 is always proportional to the speed of rotation of motor MR. This speed of rotation, in turn, is controlled by that of motor MD. The output voltage of control circuit 66 as applied to field winding 62 is equal to:

$$A(V_L - V_R \pm V_P)$$

where A —a constant; and V_L , V_R and V_P comprise direct current signals (without polarity indication) from tachometer 68, tachometer 28, and potentiometer apparatus 70.

The relays R and F are controlled by a comparator circuit 90 which effectively compares the signal V_R from tachometer 68 with signal V_L from tachometer 28. As will be seen, the comparator 90 is such that when the signal V_L increases with respect to signal V_R by a predetermined amount, the relay R is energized to cause the speed of motor MR to decrease. As the speed of motor MR decreases, a point will be reached where the signal V_R , when compared with signal V_L , indicates that the coil has reached its outer diameter, whereupon relay F will be energized to reverse motor 84 and cause motor MR to increase its speed. During this time, of course, the coil within receptacle 18 is again decreasing in diameter.

With reference, now, to FIG. 4, the comparator circuit 90 is shown in detail. The signal V_L on leads 30 from tachometer generator 28 is applied across two voltage divider arrangements, one of which includes a manually adjustable rheostat 92 between fixed resistors 94 and 96. The other voltage divider arrangement includes a second manually adjustable rheostat 98 between fixed resistors 100 and 102. As will be seen, the rheostat 92 may be manually adjusted by the operator to vary the inner diameter of the coil formed in receptacle 18, while the rheostat 98 may be manually adjusted by the operator to vary the outer diameter of the coil thus formed. The movable tap on rheostat 92 is connected to a common or ground lead 104 through an adjustable potentiometer or pot 106 and a resistor 108. Similarly, the adjustable tap on the outer diameter of rheostat 98 is connected through pot 110 and resistor 112 to this same common lead 104. The voltages on the taps of pots 110 and 106 will vary as a function of V_L and, hence, the speed of drum 16 and the rate at which the tubing is fed into receptacle 18.

The voltage V_R from tachometer generator 68 connected to the motor MR for receptacle 18 is applied across a voltage divider arrangement comprising a manually adjustable potentiometer 114 in series with two fixed resistors 116 and 118. By varying the position of the movable tap on potentiometer 114, the operator may vary the mean position of the spiral coil as viewed in FIG. 2. The signal on the tap of potentiometer 114, which varies as a function of V_R , is compared with that on the tap of pot 110 at summing point 117. As the coil diameter increases within the receptacle 18, the speed of the receptacle will gradually decrease, meaning that the voltage V_R will also decrease.

This decrease in voltage will continue until the voltage on the tap of potentiometer 114, as compared with that on the tap of pot 110, reaches the point where a transistor

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switch 120 is triggered. The transistor switch, for example, may comprise any type of bistable circuit which switches from one stable state to another in response to variations in an input signal above or below a predetermined limit.

When the transistor switch 120 is thus triggered, it energizes relay R1 which, in turn, opens its normally closed contacts 122 and closes its normally open contacts 124. It should be noted that prior to energization of relay R1, the contacts 122 were closed and, hence, relay R was energized through contacts 122 and contacts 126 of relay F which, at that time, was deenergized. This is in accordance with the foregoing explanation wherein relay R is energized during increasing coil diameter while relay F is energized during decreasing coil diameter.

Assuming, again, that relay R1 is energized and that contacts 124 close, relay T will now be energized through contacts 124 and contacts 128 of relay R, which is now deenergized since contacts 122 have opened. The relay T, being a time delay relay, does not immediately close its contacts 130. Hence, at this precise time, neither of the relays R and F are energized and the speed of receptacle 18 is neither increasing nor decreasing with respect to the drum 16, whereby the coil formed in the receptacle 18 can "tighten up" before starting its inward excursion. After the time delay t as shown in FIG. 3, the relay T closes its normally open contacts 130, thereby energizing relay F through contacts 132 of relay R, which are now closed since relay R is deenergized. When relay F becomes energized, it opens contacts 126, and causes the speed of motor MR to increase through contacts 88, motor 84 (FIG. 1) and circuit 70. Hence, the system is now beginning that part of the cycle wherein the coil diameter is decreasing.

As the coil diameter decreases, the voltages V_R and V_L will be such that the transistor switch 120 will no longer energize relay R1. Consequently, contacts 122 close and contacts 124 open. Closure of contacts 122, however, cannot energize the relay R since contacts 126 are now open. At the same time, relay T will remain energized to energize the relay F through contacts 128 of relay R and normally closed contacts 138 of relay R2 which is now deenergized. As the coil continues its inward excursion, the voltage V_R relative to the voltage V_L will increase in the negative direction as viewed in FIG. 3 until a point is reached where the voltage on the tap of potentiometer 114 as compared with that on the tap of pot 106 at summing point 134 causes a second transistor switch 136 to energize the relay R2. When relay R2 becomes energized, contacts 138 open and contacts 140 close. When contacts 138 open, they serve to deenergize relay T which, because its contacts 130 are now open, deenergizes relay F to close contacts 126. With contacts 126 and 140 now closed, the relay R becomes energized to cause the speed of motor MR to decrease, whereupon the diameter of the coil increases to the point where relay R1 is again energized and the cycle is repeated. The generator control circuit 66 of FIG. 1 is shown in detail in FIG. 5 and includes an operational amplifier 141 having a resistive feedback path 142. The signals V_L , V_R and V_P are all applied to the input of the operational amplifier 141 through resistors 144, 146 and 148, respectively. The output of the operational amplifier, V_O , is thus equal to:

$$V_L - V_R \pm V_P$$

Unless the speed of drum 16 is increasing or decreasing, the signal V_R will normally balance V_L , and the speed of motor MR will be controlled in accordance with variations in V_P as shown in FIG. 3. The output voltage V_O is applied to a thyristor magnetic gating amplifier 150 which, in turn, controls a silicon controlled full-wave rectifier 152 to supply a potential to the field winding 62 of generator GR proportional to the signal V_O .

Although the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in

form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

We claim as our invention:

1. In a system of the type in which a continuous workpiece wound about a rotating drum is discharged into a rotating receptacle to form spiral layers of the continuous workpiece; the combination of first electrical motor means for forcibly rotating said drum, second electrical motor means for rotating said receptacle, means for generating a first electrical signal V_L which varies as a function of the speed of the first motor means, means for generating a second electrical signal V_R which varies as a function of the speed of the second motor means, and control circuit apparatus responsive to said first and second electrical signals for causing said second electrical motor means to cyclically increase and decrease its speed with respect to said first motor means whereby a first spiral layer of increasing diameter will be formed in said receptacle when the speed of the second motor means decreases with respect to that of the first motor means and a second spiral layer of decreasing diameter will be formed over the first layer in the receptacle when the speed of the second motor means increases with respect to that of the first motor means.

2. The system of claim 1 wherein the means for generating said first and second electrical signals comprises tachometer generators mechanically connected to said first and second electrical motor means, respectively, and wherein the speed of said second motor means is caused to cyclically increase and decrease by a rotatable motor-operated potentiometer controlled by comparison of said first and second electrical signals.

3. The system of claim 2 wherein the control circuit apparatus rotates said motor-operated potentiometer in one direction to cause the speed of the second motor means to increase with respect to the speed of said first motor means, the control circuit apparatus rotating the motor-operated potentiometer in the other direction to cause the speed of the second motor means to decrease with respect to that of the first motor means.

4. The system of claim 1 including a rotatable payoff table for feeding the workpiece in coil form to the rotating drum through a reducing die, and including means responsive to said first electrical signal for regulating the rotary speed of said payoff table as a function of the speed of said first electrical motor means which rotates said drum.

5. The system of claim 4 and including means for varying the speed of said payoff table as a function of the instantaneous diameter of the workpiece as it issues from the coil on the payoff table in traveling to the rotating drum through said reducing die.

6. The system of claim 1 wherein the electrical signals V_L and V_R are voltages which vary in magnitude as a function of the speeds of said first and second electrical motor means respectively, and including apparatus controlled by comparison of the voltages V_L and V_R for producing a voltage V_P which cyclically increases and decreases above and below zero voltage, and means for controlling the speed of said second electrical motor means as a function of a voltage proportional to:

$$V_L - V_R \pm V_P$$

7. The system of claim 6 wherein said second electrical motor means is a direct current motor driven by a direct current generator having an external field winding, and wherein the voltage proportional to $V_L - V_R \pm V_P$ is applied to said external field winding for the generator.

8. The system of claim 6 wherein the voltage V_P is produced by a potentiometer connected to a reversible potentiometer drive motor, and wherein the potentiometer drive motor is caused to rotate in one direction when the voltage V_R increases in magnitude to an upper predetermined limit, the potentiometer drive motor being caused to rotate in the opposite direction when the magnitude of the voltage V_R decreases to a lower predetermined limit.

9. The system of claim 8 wherein the upper and lower magnitudes of the voltage V_R at which the potentiometer drive motor is caused to reverse are dependent upon the instantaneous value of the voltage V_L .

10. The system of claim 1 wherein said control circuit apparatus compares the magnitudes of the signals V_L and V_R to cause said second electrical motor means to cyclically increase and decrease its speed with respect to the first motor means.

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