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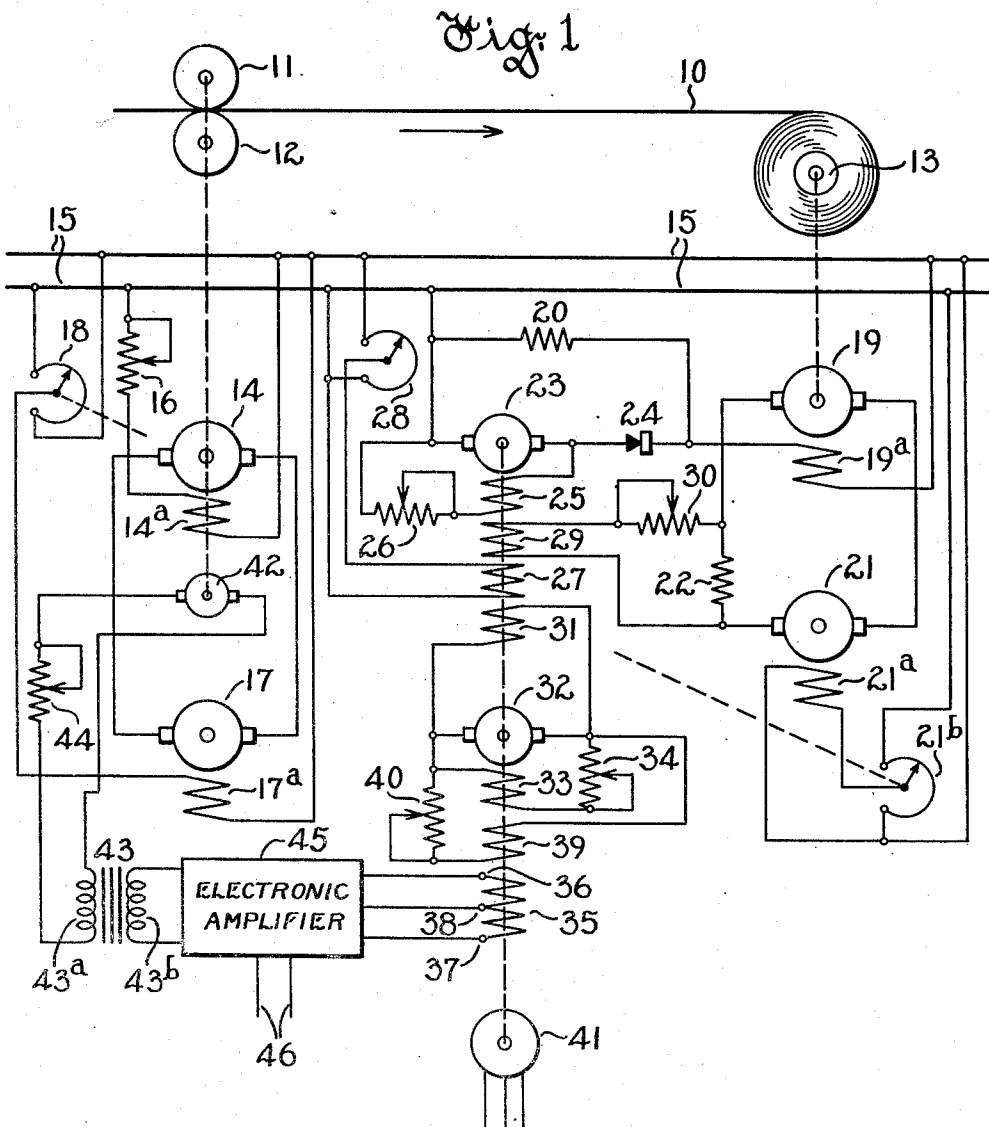
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2,697,807

MOTOR CONTROL SYSTEM FOR MAINTAINING TENSION

Filed Sept. 15, 1949

3 Sheets-Sheet 1



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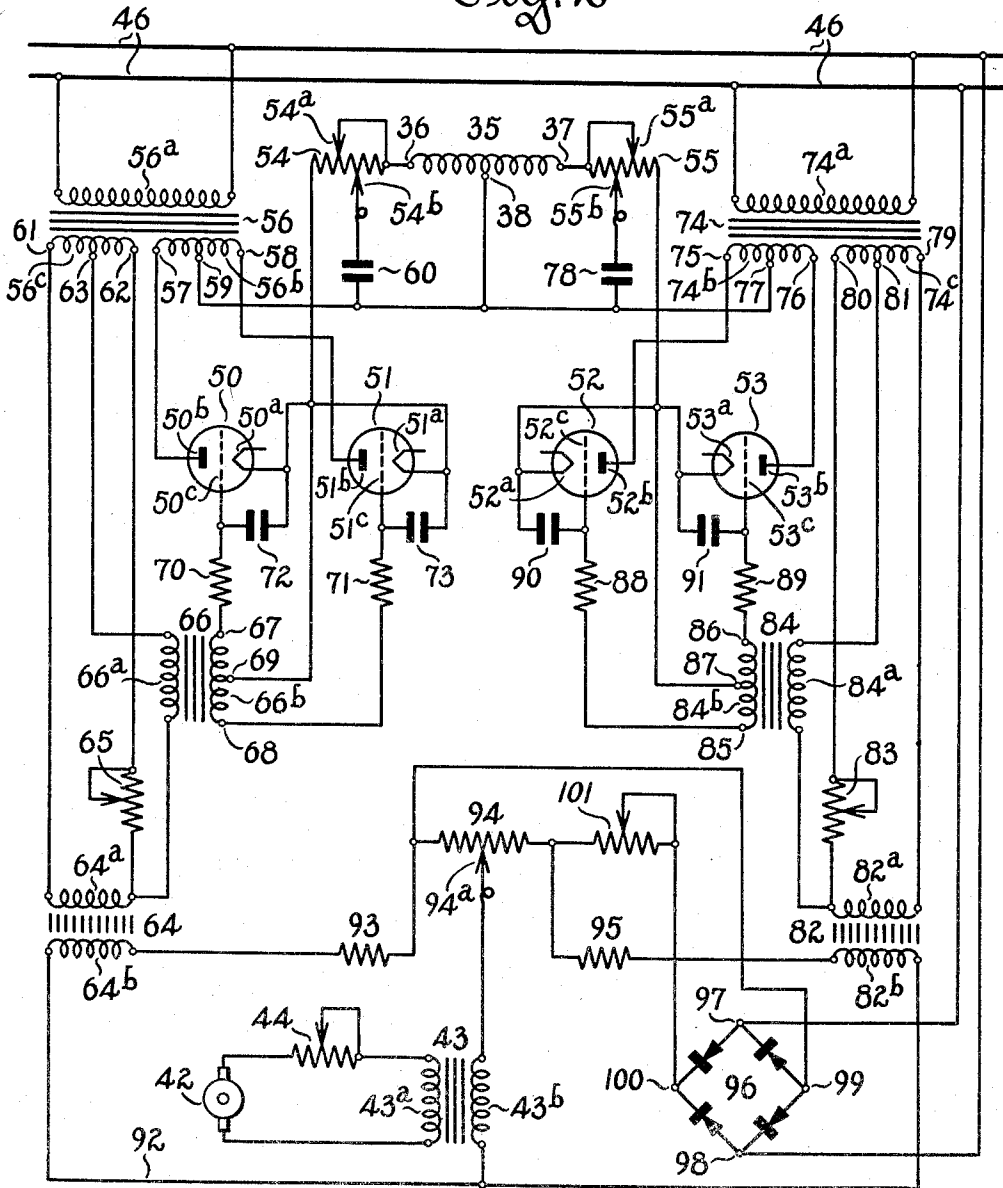
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Fig. 2



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Fig. 3

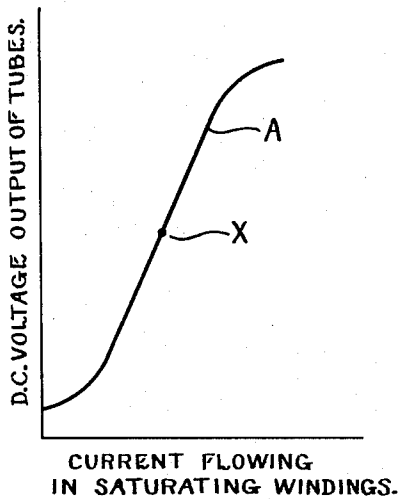


Fig. 4

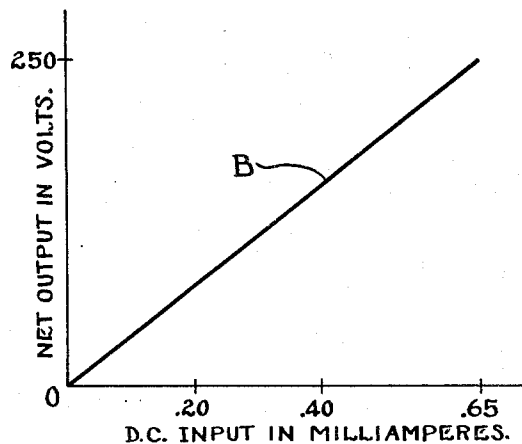
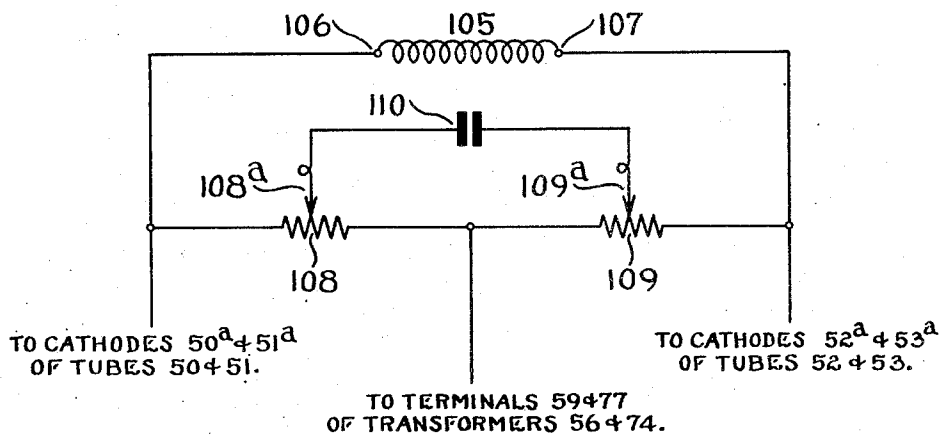


Fig. 5



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MOTOR CONTROL SYSTEM FOR MAINTAINING TENSION

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4 Claims. (Cl. 318—7)

This invention relates to a control system for electric motors, and more particularly to a tension control system for reel motors.

In the processing of sheet material, such as in the reducing and tempering of a long trip of sheet steel following annealing thereof, the material is passed through a mill and coiled up in a roll on a reel driven by an electric motor. During such processing the material is advanced to the reel by the movement imparted by the mill work rolls which are usually driven by another electric motor. To insure uniformity of quality throughout the length of material during such an operation, it is required that the material be coiled under constant or substantially constant tension. At the start of such an operation, after the material has been threaded through the mill work rolls and anchored on the coiling reel, the motor driving the mill rolls is accelerated to some preset speed. During such accelerating period of the mill motor, the material advances to the coiling reel at a speed varying as the rate of change of speed of the mill motor. Thus in order to afford coiling of the material under constant tension, the reel motor must be so controlled as to accelerate the coiling reel proportionately to the rate of change of speed of the mill motor. This also holds true when the mill motor is decelerated from its preset operating speed to rest, such as obtains at or near the end of the aforementioned processing operation.

It is a primary object of the present invention to provide a reliable and accurate control system whereby a reeling motor may be regulated to afford reeling of strip material under constant tension during accelerating and decelerating conditions of movement of the material to the reel.

Another object is to adapt a known type of control regulator for a reel motor which normally functions to effect reeling of strip material at constant tension under constant speed advance of the material to afford the aforementioned type of control.

Another object is to provide means affording corrective action of the aforementioned control regulator in relation to the rate of change of speed of the motor affording advance of the material, and

Another more specific object is to derive a control signal varying as the rate of change of speed of the motor affording advance of the material and by suitably amplifying and translating such signal to provide the aforementioned corrective action.

Other objects and advantages of the invention will hereinafter appear.

The accompanying drawings illustrate certain preferred embodiments of the invention which will now be described, it being understood that the embodiments illustrated are susceptible of various modifications in respect of their details without departing from the scope of the appended claims.

In the drawings:

Figure 1 is a diagrammatic showing of a reeling mechanism together with a control system therefor,

Fig. 2 is a diagrammatic showing of a part of the control system shown in Fig. 1,

Fig. 3 graphically depicts an electrical relationship existing in the part of the control system shown in Fig. 2,

Fig. 4 graphically depicts another electrical relationship existing in the part of the control system shown in Fig. 2, and

Fig. 5 shows a modified form of another part of the control system shown in Figs. 1 and 2.

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Referring to Fig. 1, it shows a length of material 10, such as a strip of steel, passing through mill work rolls 11 and 12 in the direction of the arrow and being coiled up on a wind-up reel 13.

The mill work rolls 11 and 12 are driven by a direct current motor 14 having a separately excited field winding 14^a. Field winding 14^a is connected across opposite sides of a source of constant direct current voltage 15 in series with an adjustable resistor 16. Power is supplied to the armature of motor 14 by an adjustable voltage generator 17, the armature of which is connected in a closed loop with the armature of motor 14. Generator 17 is provided with a separately excited field winding 17^a which is connected at one end to one side of source 15 and at its other end to an adjustable slide wire of a potentiometer rheostat 18 which is connected across opposite sides of source 15. Generator 17 is preferably driven at a substantially constant speed by any suitable driving means.

The wind-up reel 13 is driven by a direct current motor 19 having a separately excited field winding 19^a. Field winding 19^a is connected across the source 15 in series with a resistor 20. Power is supplied to the armature of motor 19 by an adjustable voltage generator 21, the armature of which is connected in a closed loop with the armature of motor 19 in series with a resistor 22. Generator 21 is provided with a separately excited field winding 21^a which at one end is connected to one side of source 15 and at its other end to the adjustable slide wire of a potentiometer rheostat 21^b which is connected across opposite sides of source 15. The slide wire of rheostat 21^b is preferably mechanically coupled with the slide wire of rheostat 18 so that movement of one will effect corresponding movement of the other. Generator 21 is preferably driven at substantially constant speed by any suitable driving means.

A bucking exciter 23 is connected across the resistor 20 in a shunt relation in series with a rectifier 24.

As will hereinafter more fully be explained, exciter 23 constitutes a current regulator for motor 19 and according to its output acts to vary the excitation of the field winding 19^a of the motor by counteracting the excitation afforded by the supply source 15. When the output of exciter 23 is high, its bucking action is high and as a result the excitation of field winding 19^a of motor 19 is low. The bucking action of exciter 23 reaches a maximum value, which because of rectifier 24, cannot be exceeded, when its output equals the voltage across the resistor 20. Conversely, when the output of exciter 23 is low, its bucking action will be low and consequently the excitation of field winding 19^a of motor 19 will be high. When exciter 23 is operating at high output voltage, reversal of current through the exciter is prevented by the rectifier 24 to insure against weakening field winding 19^a below a certain minimum value.

Exciter 23 is provided with a self-excited field winding 25 connected across its terminals in series with an adjustable resistor 26, which winding supplies the necessary ampere turns for maintaining the field of the exciter at any point within its regulating range. Further, exciter 23 is provided with a reference field winding 27 which at one end is connected to one side of the supply source 15 and at its other end to a slide wire of a potentiometer rheostat 28 which is connected across opposite sides of supply source 15. Also exciter 23 is provided with a signal field winding 29 which is connected across the resistor 22 in series with an adjustable resistor 30.

Exciter 23, as thus far described under steady state conditions, i. e., material 10 advancing from mill work rolls 11 and 12 at constant linear speed, functions in a well known manner to afford constant horsepower output of motor 19 so that the material 10 will be coiled up on reel 13 under constant tension. According to the adjustment of rheostat 28, reference field winding 27 will afford a fixed number of ampere turns which determines the maximum output of exciter 23. The signal field winding 29 provides an equal number of ampere turns for counteracting the ampere turns of the reference field winding 27. Assuming steady state conditions, when reel 13 is near empty condition at the start of reeling, the output of exciter 23 is maximum and affords maximum

bucking action. Consequently, the excitation of the field winding 19^a of motor 19 is at a minimum and the motor rotates at its high speed.

As the diameter of the coil of material 10 on reel 13 increases, motor 19 tends to decrease in speed with the result that the current flowing through the armature of the motor tends to increase. As the armature current tends to increase, the voltage drop across resistor 22 tends to increase correspondingly and as a result, the excitation of signal field winding 29 is increased to afford some small marginal increase in its number of ampere turns for counteracting the ampere turns of the reference field winding 27. As a result, the output of exciter 23 is reduced, and the excitation of the field winding 19^a of motor 19 is correspondingly increased. Increased excitation of winding 19^a increases the countervoltage in the armature of motor 19 and so the armature current is again reduced to the constant value determined by the setting of the rheostat 28.

At the start of reeling of the material 10, following threading thereof through the mill work rolls 11 and 12 and anchoring of the leading end on reel 13, the motor 14 is accelerated from rest to some preset speed, such as by appropriate adjustment of the adjustable resistor 16. In order to wind the material 10 on reel 13 at constant tension during such accelerating period of motor 14, it is necessary to increase the torque of motor 19 by an amount equal to that portion of the total torque required to effect acceleration of reel 13 and the armature of motor 19. This is accomplished in the present control system by modifying the output of exciter 23 in relation to the rate of change of speed of motor 14. The preferred additional means utilized in the present control system for effecting this type of control will now be described.

Exciter 23, in addition to its aforescribed field windings, is provided with a field winding 31 which may be termed an acceleration compensating winding. Winding 31 is connected across the terminals of an exciter 32. Exciter 32 is provided with a self-excited field winding 33 which is connected across its terminals in series with an adjustable resistor 34, said winding providing for maintaining the field of exciter 32. Further, exciter 32 is provided with a reference field winding 35 having end terminals 36 and 37 and a center-tap terminal 38. The two halves of winding 35 between the end terminals and center-tap terminal have an equal number of coil turns. Also, exciter 32 is provided with a signal field winding 39 connected across the exciter terminals in series with an adjustable resistor 40.

Exciters 23 and 32 are driven at substantially constant speed as by a motor 41 common thereto, or if desired, may be driven by driving means individual thereto.

A direct current tachometer generator 42 driven by the shaft of motor 14 is connected at its terminals to opposite ends of a primary winding 43^a of an impulse transformer 43 in series with an adjustable resistor 44. Transformer 43 also has a secondary winding 43^b which is connected to the input side of an electronic amplifier 45. Power for amplifier 45 is provided by an alternating current supply source 46. Amplifier 45 on its output side has three separate connections with the terminals 36, 37 and 38 of reference field winding 35 of exciter 32.

The output voltage of tachometer generator 42 varies directly as the speed of motor 14 and consequently the current in primary winding 43^a of transformer 43 will vary according to the speed of motor 14. During acceleration of motor 14 the flux of winding 43^a will, because of a substantial air gap in the magnetic path of the transformer, therefore, vary according to the change in speed of motor 14 and consequently the voltage induced in the secondary winding 43^b will, for a given rate of change of speed, be a certain constant value. In other words, the voltage induced in the secondary winding 43^b is proportional to the acceleration of the motor 14.

It will be appreciated that if transformer 43 is to be kept to a practical size, its output current and voltage will be relatively low. In order to make the output signal derived from transformer 43 effective for controlling the excitation of reference field winding 35 of exciter 32, I prefer to interpose the electronic amplifier 45 between the secondary winding 43^b of the transformer and the aforescribed terminals of reference field winding 35. The details and operating characteristics of amplifier 45 will now be described.

Referring to Fig. 2, it shows reference field winding 35 of exciter 32, tachometer generator 42, adjustable resistor 44, transformer 43 and alternating current supply source 46 and the various components of amplifier 45. Amplifier 45 comprises a set of electron tubes 62 and 63 of the gaseous grid controlled type connected for full wave rectification and a second set of similarly connected tubes 64 and 65. Preferably the aforementioned tubes are identical in size and in performance characteristics. Cathodes 50^a and 51^a of tubes 50 and 51 are connected to end terminal 36 of reference field winding 35, and preferably in series with a resistor 54 having adjustable slide wires 54^a and 54^b. Cathodes 52^a and 53^a of tubes 52 and 53 are connected to terminal 37 of winding 35, and preferably in series with a resistor 55 having adjustable slide wires 55^a and 55^b.

A transformer 56 is provided with a primary winding 56^a connected across opposite sides of the supply source 46 and a secondary winding 56^b which supplies power to the anodes 50^b and 51^b of tubes 50 and 51. Anode 50^b of tube 50 is connected to end terminal 57 of winding 56^b and anode 51^b of tube 51 is connected to end terminal 58 of said winding. Winding 56^b is provided with a center-tap terminal 59 which is connected to the center-tap terminal 38 of reference field winding 35 and which is also connected to the adjustable wire 54^b of resistor 54 in series with a capacitor 60. Transformer 56 is provided with another secondary winding 56^c having end terminals 61 and 62 and a center-tap terminal 63. End terminal 61 of winding 56^c is connected to end terminal 62 thereof in series with an output winding 64^a of a saturable reactor 64 and an adjustable resistor 65. Center-tap terminal 63 of said winding is connected to a point common to winding 64^a and resistor 65 in series with a primary winding 66^a of a transformer 66. Transformer 66 is also provided with a secondary winding 66^b having end terminals 67 and 68 and a center-tap terminal 69. End terminal 67 of winding 66^b is connected to a control electrode 50^c of tube 50 in series with a resistor 70 and end terminal 68 of said winding is connected to a control electrode 51^c of tube 51 in series with a resistor 71. Center-tap terminal 69 of winding 66^b is connected to cathodes 50^a and 51^a of tubes 50 and 51. Control electrode 50^c of tube 50 is connected to cathode 50^a of said tube in series with a smoothing capacitor 72, and similarly control electrode 51^c of tube 51 is connected to cathode 51^a of the latter tube in series with a smoothing capacitor 73.

Amplifier 45 is also provided with a transformer 74 having a primary winding 74^a connected across opposite sides of supply source 46 and a secondary winding 74^b supplying power to anodes 52^b and 53^b of tubes 52 and 53. Anode 52^b of tube 52 is connected to end terminal 75 of winding 74^b and anode 53^b of tube 53 is connected to end terminal 76 of said winding. Winding 74^b is provided with a center-tap terminal 77 which is connected to the center-tap terminal 38 of reference field winding 35 and which is also connected to the adjustable slide wire 55^b of resistor 55 in series with a capacitor 78. Transformer 74 is also provided with another secondary winding 74^c having end terminals 79 and 80 and a center-tap terminal 81. End terminal 79 of winding 74^c is connected to end terminal 80 of said winding in series with an output winding 82^a of a saturable reactor 82 and an adjustable resistor 83. Center-tap 81 of the latter winding is connected to a point common to winding 82^a of reactor 82 and the resistor 83 in series with a primary winding 84^a of a transformer 84. Transformer 84 is also provided with a secondary winding 84^b having end terminals 85 and 86 and a center-tap terminal 87. End terminal 85 of winding 84^b is connected to a control electrode 52^c of tube 52 in series with a resistor 88 and end terminal 86 of said winding is connected to a control electrode 53^c of tube 53 in series with a resistor 89. Center-tap terminal 87 of winding 84^b is connected to cathodes 52^a and 53^a of tubes 52 and 53. Control electrode 52^c of tube 52 is connected to cathode 52^a of said tube in series with a smoothing capacitor 90 and control electrode 53^c of tube 53 is connected to cathode 53^a of the latter tube in series with a smoothing capacitor 91.

As will be apparent to those skilled in the art, the sets of tubes 50—51 and 52—53, inclusive of their aforescribed connections, constitute two full wave rectifiers

adapted to supply direct current voltages to the terminals 36 and 37, respectively, of reference field winding 35.

Saturable reactors 64 and 82 are respectively provided with saturating windings 64^b and 82^b. It will be appreciated that the circuit comprising saturable reactor 64, winding 56^c of transformer 56, transformer 66 and adjustable resistor 65, constitutes an adjustable phase shift network which is adapted to vary the periods of conductivity of the set of tubes 50—51 by regulating the firing point of said tubes in time phase relation to the voltage applied to the anodes 50^a and 50^b of said tubes, and likewise that the circuit comprising saturable reactor 82, winding 74^c of transformer 74, transformer 84 and adjustable resistor 83 constitutes a similar phase shift network for controlling the periods of conductivity of the set of tubes 52—53 in a like manner. As will now be explained, the phase shift networks, respectively associated with each set of tubes, are adjustable by varying the currents flowing in the saturating windings 64^b and 82^b of the saturable reactors 64 and 82.

For controlling the saturating currents flowing in the windings 64^b and 82^b of reactors 64 and 82, I provide a bridge circuit in which the latter windings, and the secondary winding 43^b of impulse transformer 43 are connected. More particularly windings 64^b and 82^b are connected together at corresponding ends through a conductor 92 and are also connected together at their other ends in series with a resistor 93, an adjustable voltage divider 94 and a resistor 95; resistors 93 and 95 preferably being of the same ohmic value. Voltage divider 94 is provided with a slide wire 94^a which is connected to conductor 92 in series with the secondary winding 43^b of the impulse transformer 43. As aforesaid and shown in connection with Fig. 1, impulse transformer 43 has a primary winding 43^a supplied with voltage derived from the tachometer generator 42.

I prefer to inject a direct current reference voltage into the bridge circuit derived through the medium of a full wave, dry plate type rectifier 96. Rectifier 96 is connected to opposite sides of the supply source 46 through its terminals 97 and 98. Rectifier 96 is provided with output terminals 99 and 100; terminal 99 is connected to a point common to resistor 93 and the voltage divider 94 and terminal 100 is connected to a point common to voltage divider 94 and the resistor 95 in series with an adjustable resistor 101.

With no voltage being induced in winding 43^b of impulse transformer 43, which condition obtains under the aforesaid steady state conditions of reeling, amplifier 45 can be adjusted so that the voltage supplied by the set of tubes 50—51 to terminal 36 of reference field winding 35 of exciter 32 will be equal in magnitude to the voltage supplied by the set of tubes 52—53 to terminal 37 of said field winding. Referring to Fig. 3, it depicts the direct current voltage output of the two sets of tubes as a function of saturating current in the bridge circuit and the point X on the curve A indicates a condition of balanced voltage output of the two separate sets of tubes. Achieving such balanced voltage output of amplifier 45 may be obtained under steady state conditions as follows: The two phase shift networks respectively associated with the two sets of tubes are given a basic phase shift adjustment by appropriate adjustment of the adjustable resistors 65 and 83 so that the output potential impressed on the control electrodes of the tubes lags the potential impressed on the anodes of said tubes in phase angle by 90°. The slide wire 94^a of voltage divider 94 is then adjusted so that the current flowing through the saturating windings 64^b and 82^b are equal and so that the current flowing through winding 43^b is zero.

Adjusting slide wire 94^a in either direction from the desired point aforementioned will cause the operating point of one set of tubes to be shifted upwardly along curve A (Fig. 3) and the operating point of the other set of tubes to be shifted downwardly along curve A. As indicated, it is desired that the output voltages of both sets of tubes be the same under steady state conditions which is depicted by the point X on curve A.

As the reference field winding 35 is inductive in character, the capacitors 60 and 78 are provided to insure cut-off of the tubes 50, 51, 52 and 53 at the end of their respective conducting half cycles, proper cut-off of the tubes being obtained by appropriate adjustments of the

adjustable slide arms 54^b and 55^b along the resistors 54 and 55.

Referring to Fig. 4, the straight line B thereof depicts the overall operating characteristic of amplifier 45. Thus it will be seen that the output of amplifier in volts will vary directly as the input current throughout its operating range which is highly desirable in any electronic amplifier. In a particular embodiment of amplifier 45 tested, it was found that for a maximum input current of 0.65 milliampere at 5.7 volts, the output was 1 ampere at 250 volts, indicating an overall power amplification of 67,500 to 1.

When the voltages supplied to the terminals 36 and 37 of reference field winding 35 of exciter 32 by amplifier 45 are equal in magnitude the effective ampere turns afforded by winding 35 will be zero and as a result, exciter 32 will not supply an output voltage to winding 31 of exciter 25 for excitation of the latter winding. Under such a condition, exciter 23 controls motor 19 as hereinbefore described. During acceleration of motor 14 at the start of a reeling operation, the voltage induced in winding 43^b of impulse transformer 43 varies according to the acceleration of motor 14. This induced voltage flowing in the bridge circuit of amplifier 45 causes an unbalance of the direct currents flowing in the saturating windings 64^b and 82^b of reactors 64 and 82, that is to say, the current will be increased in one of the latter windings and correspondingly decreased in the other winding. Increase of saturating current in one such winding thus causes the phase shift network with which it is associated to be adjusted for advancing in phase angle the output voltages to the control electrodes of one set of tubes and conversely decrease in saturating current in the other of such windings causes the phase shift network with which it is associated to be adjusted for retarding in phase angle the output voltages to the control electrodes of the other set of tubes. Consequently, the voltage output of one set of tubes to one end terminal of reference field winding 35 will be increased while the voltage output of the other set of tubes to the other end terminal of the latter winding will be decreased.

When such unbalance of the voltages applied to terminals 36 and 37 of reference field winding 35 of exciter 32 occurs, this winding then has a certain net effective ampere turns and as a result exciter 34 supplies an output voltage to the field winding 31 of exciter 23. Under accelerating condition of motor 14 the excitation of winding 31 is such that it adds effective ampere turns to that afforded by the reference field winding 29 and thus the regulating action of exciter 23 is modified from that hereinbefore described under steady state conditions. The added effective ampere turns of field winding 31 effects increased bucking action of exciter 23 over that occurring during its steady state operation, and as a result, field winding 19^a is weakened to some extent. As a consequence of this weakening of the excitation of field winding 19^a, the armature of motor 19 draws more current and as a result the torque of motor 19 is proportionately increased to thereby exert the additional torque necessary for accelerating the armature of motor 19 and reel 13, thus insuring that the reeling of material 10 will keep in step with the accelerating linear speed of material 10 advancing from the work rolls 11 and 12.

As the preset speed of motor 14 is approached during its accelerating period, the rate of change of speed of said motor will decrease to zero. Thus the induced voltage in winding 43^b of impulse transformer 43 decreases accordingly and as a result, the saturating currents flowing in the windings 64^b and 82^b of reactors 64 and 82 will equalize when the preset speed of motor 14 is reached and then the output voltages to the terminals 36 and 37 of reference field winding 35 will be equal, and as aforesaid, under such condition, winding 35 will then have zero effective ampere turns. As a result, the output to winding 31 from exciter 32 diminishes to zero; the signal winding 39 through proper polarity connection and adjustment of its associated adjustable resistor 40 insuring that the output of exciter 32 will be reduced to zero whenever the reference field winding 35 thereof has zero effective ampere turns.

When motor 14 is decelerated from its preset speed to rest, the reverse action takes place. During deceleration of motor 14, the output voltage of tachometer generator 42 decreases proportionally to the speed of motor

14. Consequently, a voltage is induced in winding 43^b which varies as the rate of change in speed of motor 14. As a result, the bridge circuit of amplifier 45 is unbalanced in the opposite direction. Thus the saturating currents flowing in the windings 64^b and 82^b are again unbalanced, but reversely from that obtaining under acceleration of motor 14. As a result the voltages applied to terminals 36 and 37 of reference field winding 35 are unbalanced reversely from that obtaining under accelerating condition of motor 14. Reference field winding 35 then has a certain net effective ampere turns which cause exciter 32 to produce an output exciting voltage to field winding 31 of exciter 23. The excitation of winding 31 under decelerating condition of motor 14 is such as to subtract ampere turns from the ampere turns afforded by reference field winding 27. Consequently, the bucking action of exciter 23 is weakened below that which would obtain under steady state conditions for the diameter of the coil of material 10 then existing. Thus field winding 19^a of motor 19 will accordingly be strengthened with the result that less current will flow through the armature of motor 19 and the torque of the latter will be reduced, insuring that constant tension will be maintained on material 10 during deceleration of motor 14. As motor 14 approaches stable speed, the compensating excitation of field winding 31 of exciter 23 will diminish accordingly.

The compensating excitation of field winding 31 is thus made proportional to the rate in change of speed of motor 14 during acceleration and deceleration of the latter, thereby insuring that the material 10 will be coiled on wind-up reel 13 under constant tension during such periods for any rate of change of speed as well as under steady state conditions of reeling.

It will be appreciated that although the control system hereinbefore described has been depicted in conjunction with a motor driving a wind-up reel, it is equally adaptable for use in conjunction with a motor driving a take-off or supply reel, such as would afford supply of the material 10 to the mill work rolls 11 and 12. In actual practice such control system would preferably be used in conjunction with both the take-off reel and wind-up reel driving motors.

Whereas exciter 32 as hereinbefore shown and described is provided with a center-tap reference field winding 35, if it is not convenient to provide an exciter with such type of winding, the present control system may also be used where the reference field winding is of the non-center-tapped type with certain modifications in its circuit connections with amplifier 45 as will now be described. Referring to Fig. 5, it shows a reference field winding 105 which may be used in the place of the reference field winding 35 in exciter 32. Winding 105 is provided with end terminals 106 and 107 and terminal 106 thereof is connected to cathodes 50^a and 51^a of tubes 50 and 51, while terminal 107 is connected to cathodes 52^a and 53^a of tubes 52 and 53. A pair of adjustable ballast resistors 108 and 109 are connected across terminals 106 and 107 of winding 105 and a point common to said resistors is connected with terminals 59 and 77, respectively, of the secondary windings 56^b and 74^b of transformers 56 and 74. A capacitor 110 is connected between the adjustable slide wires 108^a and 109^a of ballast resistors 108 and 109.

Where a reference field winding like the field winding 105 is used in conjunction with exciter 32 and is connected in circuit with amplifier 45 as above described, its excitation will be similar to that for reference field winding 35. If the voltage output of the two sets of tubes 50—51 and 52—53 are equal, the voltage applied to terminals 106 and 107 of winding 105 will be equal and as a result, no current will flow in the winding 105 and consequently the latter will then have zero effective ampere turns. Unbalanced output voltages from the two sets of tubes will cause current to flow in winding 105 in a direction depending upon the direction of voltage unbalance between the two sets of tubes, and under the latter condition winding 105 will have effective ampere turns depending on the degree and direction of such unbalance of the voltages applied thereto.

I claim:

1. The combination with an electric motor, a generator supplying the armature of said motor, a source of power for the field winding of said motor, a regulator comprising an exciter having its armature connected in circuit with the field winding of said motor and having a field winding connected to be responsive to the armature

current of said motor for maintaining said armature current at a predetermined value, a second electric motor, and means for controlling the speed of said second motor, of a second field winding for said exciter, and means for energizing said second field of said exciter in accordance with the rate of change of speed of said second motor and its direction for varying the armature current of the first motor, said means comprising a generator driven by said second motor, a transformer having a primary winding connected to the last mentioned generator and having a secondary winding, and electronic amplifying means having connection with the transformer secondary winding and controlling the energization of said second field winding of said exciter.

2. The combination with an electric motor, a generator supplying the armature of said motor, a source of power for the field winding of said motor, a regulator comprising an exciter having its armature connected in circuit with the field winding of said motor and having a field winding connected to be responsive to the armature current of said motor for maintaining said armature current at a predetermined value, a second electric motor, and means for controlling the speed of said second motor, of a second field winding for said exciter, and means for energizing the second field winding of said exciter comprising a second exciter having its armature connected to the latter field winding and having a field winding to be controlled, a generator driven by said second motor, a transformer having a primary winding connected to the last mentioned generator and having a secondary winding, and an electronic amplifier having connection with the transformer secondary winding and the field winding of said second exciter and affording energization of the latter field winding in accordance with the rate of change of speed of said second motor and its direction to thereby afford corresponding energization of the second field winding of said first exciter for effecting variation in the armature current of said first motor.

3. The combination with an electric motor, a generator supplying the armature of said motor, a source of power for the field winding of said motor, a regulator comprising an exciter having its armature connected in circuit with the field winding of said motor and having a field winding connected to be responsive to the armature current of said motor for maintaining said armature current at a predetermined value, a second electric motor, and means for controlling the speed of said second motor, of a second field winding for said exciter, and means for energizing the second field winding of said exciter for effecting variation in the armature current of said first motor and comprising, a second exciter having its armature connected to the second field winding of the first exciter and having a field winding provided with end terminals and a center-tap terminal, a generator driven by said second motor, a transformer having a primary winding connected to the last mentioned generator and having a secondary winding, and an electronic amplifier having input connections with the transformer secondary winding and having output connections with the end and center-tap terminals of the field winding of said second exciter, said amplifier affording energization of the latter field winding in accordance with the rate of change of speed of said second motor and its direction to thereby provide for corresponding energization of the second field winding of said first exciter.

4. In combination, an electric motor, means for controlling the speed of said motor, a generator driven by said motor, a transformer having a primary winding connected to said generator and having a secondary winding, a source of alternating current power, a source of constant direct current voltage, an exciter having a field winding affording control of the output of said exciter according to its excitation, and an amplifier comprising two separate full wave rectifying means deriving power from the first mentioned source for supplying the end terminals of the exciter field winding respectively with rectified voltages, separate phase shift networks individualized to said rectifying means and deriving power from said first mentioned source for controlling the level of the rectified voltage supplied by said rectifying means, said phase shift networks each having a saturable reactor, and a circuit including the saturating windings of said reactors and having connections with the second mentioned source and the transformer secondary winding, said circuit affording in accordance with the rate of change of speed of

said motor for flow of unbalanced currents through said reactor saturating windings to thereby provide corresponding unbalance between the rectified voltages supplied by said two rectifying means to said exciter field winding.

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Crever	June 29, 1948
Bachelor	July 19, 1949
Jolly	May 16, 1950
Hunt	June 29, 1952