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F. E. McLANE

ELECTRIC APPARATUS FOR CONTROLLING
CORE-TYPE REEL DRIVES

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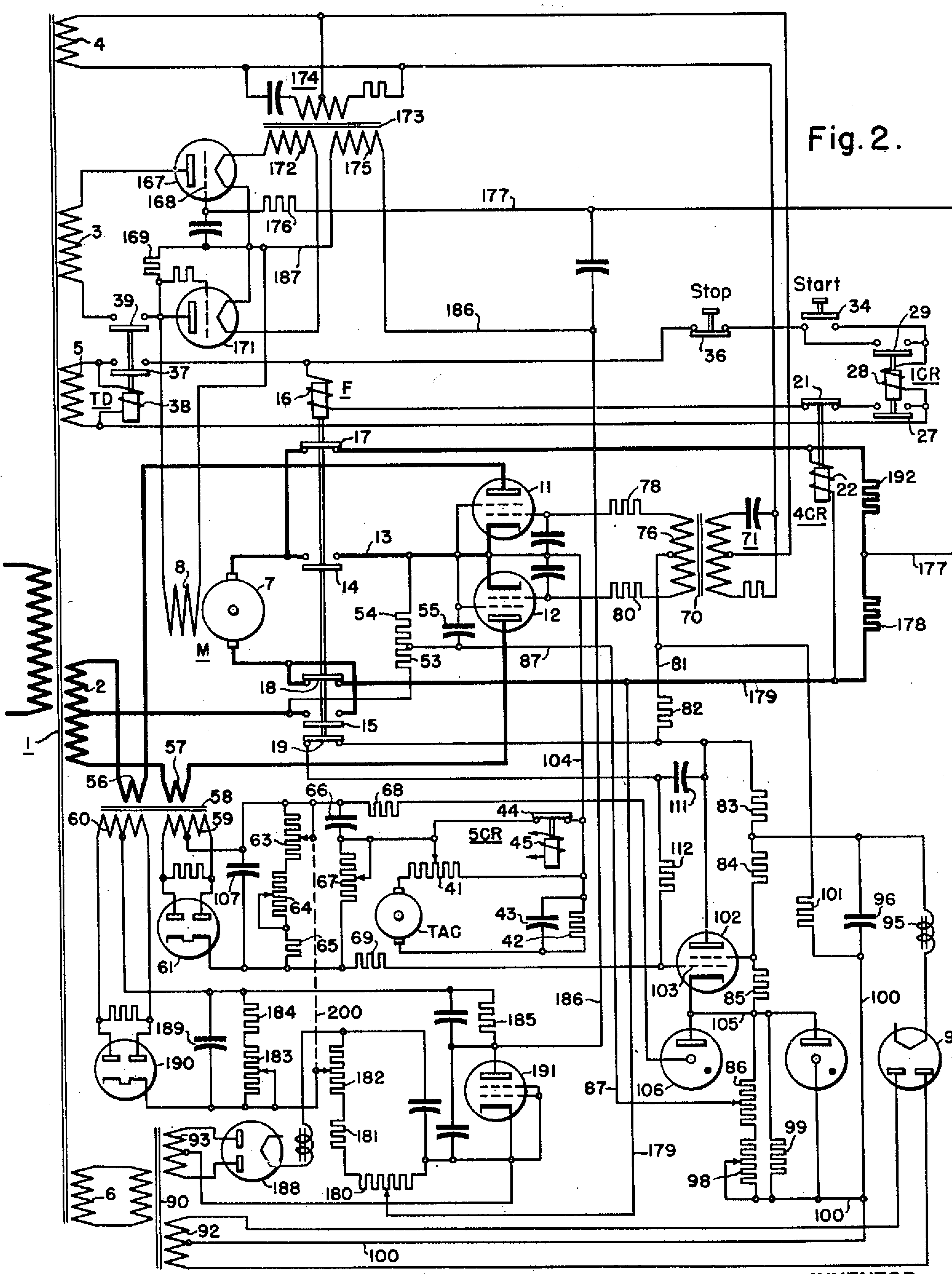

Fig. 2.

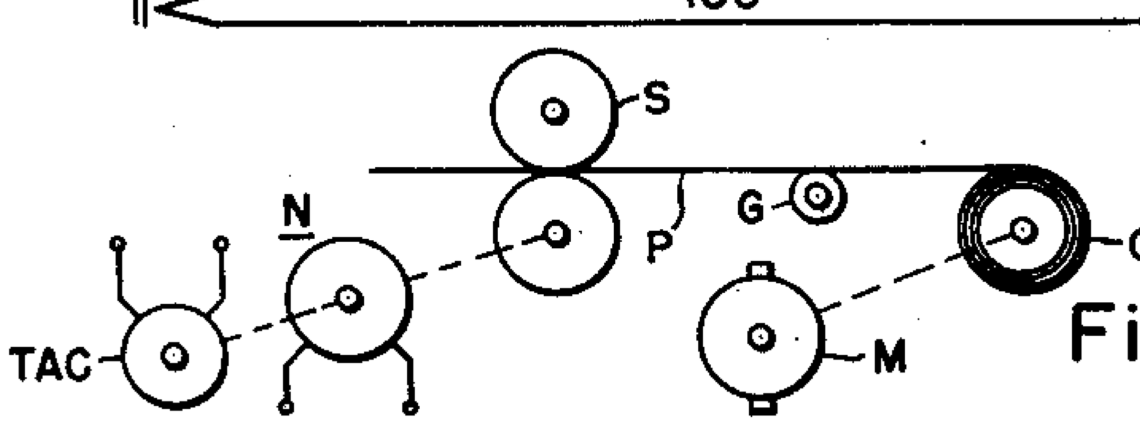

Fig. 1.

INVENTOR
Fletcher E. McLane.
BY C. M. Avery
ATTORNEY

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ELECTRIC APPARATUS FOR CONTROLLING CORE-TYPE REEL DRIVES

Fletcher E. McLane, Lancaster, N. Y., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

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My invention relates to control systems or apparatus for operating a direct-current motor for a core-type reel drive from an alternating-current line while controlling and regulating the revolving speed of the drive to automatically maintain the tension in the reeling material within given limit values while the reel diameter is changing.

It is an object of my invention to provide a reel drive control system that not only affords an accurate maintenance of substantially constant tension in the winding material over a wide range of speeds or reel diameter ratios but also secures an accurate adaptation of the reel base speed to that of another machine or section of the machinery to which the reel drive is to be applied while permitting a selective adjustment of the value of tension to be kept constant in the material regardless of changes in that speed.

Another object of my invention is to achieve in such control systems a reeling operation under satisfactory tension conditions of the reeling material over a wider range of reel revolving speeds and reel build-up diameters than heretofore obtainable in systems of otherwise comparable performance. For instance, if the normal build-up ratio of such a system is 4 to 1, the invention aims at considerably increasing this ratio to a maximum of 6 to 1 or 8 to 1 with the aid of simple devices requiring no appreciable additional expenditure in material or space requirements.

It is also an object of my invention to provide a winder drive control system of the above-mentioned kind in which, when the reel build-up should exceed the design limits, the occurrence of excessive tension in the material is prevented thus avoiding the damage to the reeling material apt to occur in known systems under such conditions.

These and other objects, as well as the means provided by an invention for achieving them, these means being set forth with particularity in the appended claims, will be apparent from the following description of an embodiment of the invention in conjunction with the drawings, in which:

Figure 1 shows a schematic diagram of sectional fabricating machinery including a reel drive, and

Fig. 2 shows a schematic circuit diagram of the reel drive embodying the features of the invention.

The illustrated system is designed to operate

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a core-type reel drive which forms part of a fabricating line and receives the material to be wound from a separately driven machinery section whose speed determines the linear travelling speed of the material. The winding operation is to be controlled to secure substantially constant tension in the material being wound. Consequently, the speed of the reel drive motor must decrease as the reel of wound material is building up.

The schematic diagram of Fig. 1 represents such a reel drive and will facilitate understanding the detailed illustration of the drive control scheme shown in Fig. 2. According to Fig. 1, the material P being fabricated, such as a paper sheet passes through a machinery section S, such as a calender, over a guide roller G and is wound up on the core C of a reel drive. The drive motor N of section S may be adjustable to a desired constant speed value, and this value determines the linear travelling speed of the material P. The reel drive motor M is separately energized and must be so controlled that its speed depends upon that of the section drive motor N but decreases during the winding operation as the reel of material is building up on the core C, so that the tension in the material remains within desired limits. In order to provide the control circuits for the reel drive motor M with a signal voltage indicative of the speed of the section motor S, a voltage source indicative of the section speed is provided. This source, in the illustrated sample, is a tachometer generator TAC which is mechanically driven from the section drive motor N and forms part of the control system of motor M as will be explained in a later place.

In the following description of Figure 2 parenthetical references are given to specific commercial type designations of electronic tubes and to numerical values of circuit parameters. It will be understood, however, that these references are given merely by way of example and that different tubes and different parameter values may be employed, depending upon the requirements and selected circuit connections of each particular application. The circuit parameter values, in particular, should be considered to exemplify orders of magnitude or suitable relative dimensions rather than obligatory quantities. The term "voltage source," in the following description and in the appended claims, is used in its broader sense to include not only primary sources such as a generator but also any circuit element acting as a secondary source to impress a voltage on a circuit.

The illustrated system, according to Figure 2, is energized from an alternating-current line through a main transformer 1, with secondary windings 2, 3, 4, 5 and 6. The direct-current motor M to be controlled has its armature 7 energized from the secondary winding 2 (500 volts) and is equipped with a separately excited field winding 8.

The armature circuit of the motor includes two controllable rectifier tubes 11 and 12. These tubes consist preferably of thyratrons (type WL-624). For large motors, ignitrons may be used instead, and the firing angle of the ignitrons may then be controlled by thyratrons whose control or grid circuits are then designed and operative substantially in the manner described below. The tubes 11 and 12 have a common cathode lead 13 in connection with one terminal of the armature 7. The other armature terminal is connected to the midpoint of secondary 2. The respective anodes of tubes 11 and 12 are in connection with the respective two end points of secondary 2.

The armature circuit is controlled by the main contacts 14 and 15 of a contactor F whose magnet coil 16 also actuates three auxiliary contacts 17, 18 and 19. The coil circuit for contactor F is energized from transformer secondary 5 and extends through the contact 21 of a relay 4CR with a coil 22, and also through a contact 27 of a control relay 1CR with a coil 28 and a self-holding contact 29. The coil circuit of relay 1CR includes a normally open "Start" contact 34 and is energized from the secondary 5 through a normally closed "Stop" contact 36. The coil circuits of relays 1CR and F also include the normally open contact 37 of a timing relay TD whose coil 38 is energized from secondary 5 whenever the transformer 1 is energized. Relay TD has another normally open contact 39 in the circuit of the secondary winding 3.

As mentioned, a tachometer generator TAC is mechanically connected with the drive motor (N in Fig. 1) of another machinery section. Generator TAC impresses a speed-proportional voltage across a circuit (Fig. 2) composed of a sensitivity control rheostat 41 (25,000 ohms) and a resistor 42 (33,000 ohms), a capacitor 43 (2 mfd.) being parallel connected to resistor 42. The voltage tapped off between the slider of rheostat 41 and the resistor 42 serves for controlling the armature rectifiers in response to the linear traveling speed of the material to be wound as will be later explained. The illustrated embodiment is provided with an electromagnetic relay 5CR whose contact 44, when closed, short circuits the tapped off portion of rheostat 41 to automatically set the system for zero speed. The circuit (not shown) of coil 45 of relay 5CR is controlled in dependence upon the operation of the section motor (N in Fig. 1). Coil 45 is energized and contact 44 is open when that section motor (N) is running and coil 45 is deenergized and contact 44 is closed when the motor (N) is denergized or stopped.

Two resistors 53 and 54 (together 15,000 ohms) are series-connected with each other across the armature 6 through contacts 14 and 15 when contactor F is in picked-up condition. The two resistors 53 and 54 form a voltage divider so that the voltage drop across the resistor 54 has a given proportion to the armature voltage of the motor. As will be explained in the following, this voltage drop is also effective in the tube control circuits for regulating the motor speed. A filtering capacitor 55 (2 mfd.) is connected across resistor 54.

Connected between the anodes of tubes 11 and 12 and the respective ends of the secondary 2 are two primary windings 56 and 57 of a current transformer 58 with two secondary windings 59 and 60. The secondary windings of transformer 58 provide respective voltages, proportional to the current in the armature circuit. The current-measuring voltage from secondary 59 is rectified by a twin rectifier 61. The rectified voltage is impressed across a series arrangement of two rheostats 63 (5,000 ohms), 64 (5,000 ohms) and a resistor 65 (470 ohms). The voltage taken from across the adjusted portion of rheostats 63, 64 and resistor 65 is also effective in the tube control circuits for the purpose of current limiting and acceleration control, as will also be explained below. A capacitor 66 (0.5 mfd.) is series-connected with a resistor 67 (10,000 ohms) across the series arrangement of resistance elements 63, 64 and 65. The just-mentioned current-responsive reference voltage is applied to the rectifier-controlling tube circuits through series resistor 68 (47,000 ohms) and 69 (150,000 ohms).

A grid circuit transformer 70 has its primary energized through a phase shift circuit 71 from the secondary 4 of transformer 1 and has a mid-tapped secondary 76 which forms part of the control or grid circuits of the armature rectifier tubes 11 and 12. One end of secondary 76 is attached to the control grid of tube 11 through a resistor 78 (220,000 ohms). The other end of secondary 76 is attached to the control grid of tube 12 through a resistor 80 (220,000 ohms).

The control circuit for tubes 11 and 12 extends through respective resistors 78 and 80 to the secondary 76, thence through a lead 81 and a resistor 82 (100,00 ohms) to a load resistor 83 (20,000 ohms). Thence through resistors 84 (7,500 ohms) and 85 (1,900 ohms) to a stalled-tension control rheostat 86 (10,000 ohms) and from the tap of this rheostat through a lead 87 and through resistor 54 to the common cathode lead 13 of the armature rectifier tubes.

The just-mentioned control circuit for armature rectifier tubes 11 and 12 includes the following sources of component grid voltage:

(*a*1) A first source is represented by the secondary 76 of the grid transformer 70. This source impresses on the grids of the two tubes an alternating component grid voltage which is about 90° dephased relative to the anode voltage of the respective tubes.

(*a*2) A second source of component grid voltage is represented by the totality of series-connected resistors 82, 84, 85 which provide a direct-current bias voltage essentially controlled by the voltage drop across the resistor 82 while the voltage drop across resistors 84 and 85 is negligible for the control circuit of the armature rectifiers and serves to provide a constant bias for the screen grid of the master control tube 102 described below. The just-mentioned resistors are impressed by voltage derived from a transformer 90 whose primary is connected to the secondary 6 of the main transformer 1 and which has two secondaries 92 and 93. The voltage (1080 volts) from secondary 92 is rectified by a twin diode 94 (type 5Y3) and smoothed by means of a filtering reactor 95 (10 henries) and a filter capacitor 96 (8 mfd.). The filtered direct-current voltage is applied across a potentiometric resistance circuit which includes the resistors 84 and 85 in series with the rheostat 86 and in series with another rheostat 98 (10,000 ohms), the rheostats 86 and 98 being parallel by a resistor 99 (5,000 ohms). The common terminal of rheostat 98 and resistor 99 is connected by a lead 100 to the other pole of the just-mentioned rectifier and filter equipment. A resistor 101 (10,000 ohms) is connected between the grid lead 81 of the armature rectifiers and the negative end (lead 100) of the constant voltage source (rectifier 94). The resistors 82 and 101 form part of a voltage divider which permits the grid lead 81 to go negative as well as positive with respect to the cathode lead 13 of the armature rectifiers.

(a3) A third source of component grid voltage for the armature rectifier tubes is represented by the load resistor 83. The voltage impressed on the control circuit from across resistor 83 is unidirectional and of variable magnitude. It raises or lowers the above-mentioned periodic grid bias and thereby advances or delays the firing points of tubes 11 and 12, thus varying the voltage applied to the motor armature to control the motor speed. The speed control voltage appearing across resistor 83 is produced and controlled in the following manner. Resistor 83 is connected as a load in the plate circuit of a master control tube 102 which operates as an amplifier and consists preferably of a vacuum tube, such as a pentode (type 6V6). The control grid of the master tube 102 is denoted by 103. The plate circuit of tube 102 extends in series through resistors 83, 84 and 85 and is energized across resistors 84, 85 from the constant voltage supply (rectifier 94, etc.). It will be recognized that the voltage drop across the load resistor 83 depends upon the conductance of the master tube 102 and, consequently, upon the voltage conditions in the grid circuit of the master tube 102 which will be described in a later place.

The above-mentioned three voltage sources (a1), (a2), (a3) essentially determine the operating condition of the armature rectifier tubes 11 and 12. Since the values of the voltages from sources (a1) and (a2) are normally fixed, the operation of tubes 11 and 12 depends substantially only on the voltage drop across the load resistor 83 and hence on the grid control condition of the master tube 102. This is true, despite the fact that two other voltages are also impressed on the control circuit of the armature rectifier tubes across resistor 54 and rheostat 98, respectively. These other voltages are not only of a smaller order of magnitude than the voltages from sources (a1), (a2) and (a3) but also oppose and substantially cancel each other so that they have no appreciable control effect on the armature rectifier tubes and may be neglected as far as the control performance of the control circuit for the armature rectifier tubes is concerned.

It has been mentioned that the conductance of the armature rectifier tubes depends essentially only on the voltage variations across the resistor 83 which, in turn, are controlled by the voltage conditions in the grid circuit of the master tube 102. The master tube grid circuit extends from grid 103 through resistor 69 and rheostat 67, thence through part of the tachometer-energized rheostat 41, lead 104, rectifier cathode lead 13, resistor 54, lead 87 and the upper portion of rheostat 86 to the cathode lead 105 of the master tube 102. Also connected with this grid circuit are current limiting means still to be described.

This master tube grid circuit includes three series-connected sources (b1), (b2), (b3) of component grid voltages:

(b1) A first source is represented by the tachometer rheostat 41, contact 44 being open during normal operation. The tapped-off portion of rheostat 41 provides a unidirectional voltage whose normally constant magnitude depends upon the speed of the section motor (N, Fig. 1) and determines the base speed of the reel drive motor M.

(b2) A second source of grid voltage for the master tube 102 is represented by the armature shunt resistor 54. As explained, the voltage across this resistor is proportional to the armature voltage of the reel drive motor M. The polarity of connection is such that the voltage from resistor 54 is in series opposition to the speed control voltage from rheostat 41. When the motor armature voltage as measured by the voltage drop across resistor 54, has a value determined by the normally constant voltage drop across the active portion of rheostat 41, then the two voltages from sources (b1) and (b2) cancel each other to such an extent that a resultant small negative bias, for instance of a few volts, is impressed on the master tube 102 substantially as needed to maintain a constant value of armature voltage. If the armature voltage exceeds that value, the resultant bias voltage on the grid 103 of master tube 102 becomes more negative so that the voltage drop of resistor 83 is changed toward delaying the firing point of the armature rectifiers, thus returning the motor armature voltage to the correct value. If the armature voltage drops below the proper value, the reverse control action takes place so that the armature rectifier tubes advance their firing points and increase the armature voltage to restore the correct value. Thus the sources (b1) and (b2) act to regulate the motor for constant armature voltage.

(b3) A third source of voltage in the master tube grid circuit is represented by the rheostat 86. The voltage drop across this resistor has an adjusted constant small value. When the machinery is at standstill and the active portion of rheostat 41 shorted by the then closed contact 44 of relay 5CR, the small voltage from rheostat 86, opposing that from resistor 54, remains effective and thus provides for a desired stalled tension in the material. The value of this stalled tension can be adjusted by setting the slider of rheostat 86.

As mentioned, the master tube grid circuit is also connected with current limiting means which have a controlling effect on the armature rectifier tubes only when the armature current of the controlled motor M reaches a preset value. These current limiting means will be described presently.

As, during the starting period, the current in the armature gradually increases, the current through the resistance circuit 63—64—65 increases in direct proportion. One end of this resistance circuit is connected through resistor 69 to the grid 103 of the master tube 102, and the slider of rheostat 63 is connected through resistor 68 to the cathode of a glow-discharge tube 106 (VR 150). When the difference of potential across the effective resistance circuit 63—64—65 becomes equal to the breakdown voltage (150 volts) of the glow tube 106, this tube becomes conductive, thus connecting the slider of rheostat 63 to the cathode of the master tube 102 through a constant difference of potential in tube 106. Any further increase in the voltage difference between ends of the resistance circuit 63—64—65 makes the grid 103 of the master tube more positive, thus increasing the plate current of the master tube. This increases the voltage drop across the tube load resistor 83 and causes the grid lead 81 of the armature rectifier tubes 11, 12 to go negative, thus reducing the voltage and current of the armature circuit. In this manner, the current that can flow through the armature circuit is limited to a value predetermined by the selected setting of the slider of rheostat 63. This current limiting action not only secures a smooth acceleration but has also an essential regulating effect during normal winding performance as will be later explained with reference to the operation of the system as a whole.

The capacitor 66 is series connected with resistor 67 across the filtering capacitor 107 (2 mfd.) to prevent a sluggish response of the current limit control that may otherwise be caused by time delay due to charging and discharging of the filter capacitor 107 during rapid changes in motor load current as is more fully explained in U. S. Patent 2,516,568 of J. G. Haneiko assigned to the assignee of the present invention.

A capacitor 111 (.1 mfd.) and a resistor 112 (47,000 ohms) are connected in series with each other between the anode and the control grid 103 of master tube 102. Capacitor 111 is shorted through contact 19 of contactor F as long as the motor M is deenergized. At the starting moment of the motor, i. e., when contactor F closes, the short circuit across capacitor 111 is eliminated. At that moment, the grid voltage of master tube 102 has a high value substantially determined by the voltage from rheostat 41. From this high initial value the grid voltage gradually declines and correspondingly reduces the voltage drop of plate load resistor 83 to advance the firing point of the armature rectifiers. However, since the capacitor 111 is now subject to the voltage between grid and anode of tube 102, the charge drained into the capacitor delays the decline in grid voltage and, consequently, also delays the advance of the firing points of the armature rectifiers. This effect ceases when the capacitor is fully charged, but the time constant of the capacitive circuit (111, 112) suffices to prevent high initial current peaks that would otherwise occur immediately subsequent to the starting moment. Therefore, the capacitor 111 and resistor 112 provide a negative feedback circuit which improves the stability of the control and regulating performance. When the drive is stopped by actuation of the stop contact 36, the contactor F then dropping out short circuits the capacitor at contact 19. This connects the grid 103 of master tube 102 to the anode, thus forcing the tube 102 to carry high plate current and to increase the voltage drop in resistor 83. As a result, the grid lead 81 of the armature rectifiers goes negative and blocks the armature rectifier tubes. The just-mentioned features involving the capacitor 111, resistor 112 and contact 19 are in accordance with disclosure in U. S. Patent 2,488,536 of J. G. Haneiko, assigned to the assignee of the present invention.

Before further dealing with the armature rectifiers and appertaining control devices as regards their functioning in correlation to the operation of the system as a whole, a description of the field control means will presently be given.

The field winding 8 of motor M is energized from the secondary 3 (580 volts) through a controllable rectifier tube 167 (type WL–5557) whose

control grid is denoted by 168. A load resistor 169 (5,000 ohms) is connected parallel to field winding 8. Another rectifier tube 171 (type WL–5557) is connected across field winding 8 to permit the field current to persist during the nonconductive intervals of the rectifier tube 167. In this manner, the field winding 8 is energized by substantially full-wave rectified current despite the fact that only the tube 167 is subject to grid control. Heating current for the cathodes of tubes 167 and 171 is supplied from the secondary 172 of an auxiliary transformer 173 whose primary is energized through a phase shift circuit 174 from the secondary 4 of the main transformer 1. Transformer 173 has another secondary 175 (20 volts) which provides a phase-shifted alternating component grid voltage for tube 167.

The grid circuit of the field rectifier 167 extends from grid 168 through a resistor 176 (22,000 ohms), a grid lead 177, a resistor 178 (7.5 ohms), and a lead 179 to the tap of a rheostat 180 (400 ohms), thence through the left-hand portion of rheostat 180, a resistor 181 (3,000 ohms) and part of a rheostat 182 (2,500 ohms) to the appertaining slider from which the grid circuit continues through an adjustable resistor 183 (5,000 ohms), a resistor 184 (12,500 ohms), and a tube load resistor 185 (22,000 ohms) to a lead 186 connected through the secondary 175 of phase shift transformer 173 connected with the cathode lead 187 of the field rectifier.

This field rectifier grid circuit includes the following sources of component grid voltages:

(*c*1) One source is represented by the secondary 175 of transformer 173 which impresses on the field rectifier grid circuit an alternating component grid voltage phase displaced, preferably about 90°, relative to the anode voltage.

(*c*2) The second source is represented by the resistance circuit of rheostat 180, resistor 181 and rheostat 182. This circuit is connected across the output terminals of a full-wave rectifier tube 188 which is supplied from the secondary 93 of transformer 90 and impresses on the field rectifier grid circuit a constant unidirectional component grid voltage adjustable by means of the slider of rheostat 180. The selected adjustment of the slider on rheostat 182 determines the value of tension to be maintained in the winding material. Rheostat 180 permits adjusting the maximum speed of motor M.

(*c*3) The third source of component grid voltage for the field rectifier comprises the adjustable resistance circuit of resistors 183 and 184. This circuit is connected parallel to a filter capacitor 189 (2 mfd.) across the output terminals of a full-wave rectifier twin tube 190 (6x5GT) energized from secondary 60 of current transformer 58. The component grid voltage thus impressed on the grid circuit is proportional to the motor armature current and series opposed to the constant component grid voltage from source (*c*2) as adjusted by the slider of rheostat 182. Consequently, during winding operation, the current-responsive voltage from source (*c*3) is constantly compared with the adjusted constant voltage from source (*c*2). As a result, the grid circuit is controlled to regulate the field rectifier output voltage for maintenance of constant current in the armature circuit.

Aside from the voltage sources (*c*1), (*c*2), (*c*3) effective during some conditions of performance, the field rectifier grid circuit is provided with two additional grid voltage sources (*c*4), (*c*5) that are effective only under other conditions as will be described presently.

(c4) The resistor 185 is connected as an anode load in the plate circuit of a vacuum tube 191 (WL–2050). This plate circuit extends from the cathode through resistance elements 180, 181, 182, 183, 184, and 185 to the anode. An adjusted constant component of plate voltage is impressed on the tube by elements 180, 181 and 182 while another component plate voltage, proportional to the motor armature current is impressed by elements 183 and 184. As a result, the anode of tube 191 is normally negative relative to the cathode and becomes sufficiently positive only when the motor field is weakened to make the armature current exceed a given limit value. Only then can the tube 191 conduct current in the circuit 180—181—182—183—184—185 and impress a corresponding voltage drop across the load resistor 185 and on the grid circuit of the field rectifier tubes. This voltage drop of resistor 185, i. e., of source (c4), replaces or overpowers the voltage from source (c3) and keeps the field rectifier tubes 167, 171 firing at a minimum level adjustable by rheostat 180. It will be apparent, that the tube 191 and its load resistor 185 do not play part in regulating the drive system for constant winding tension but performs a speed limiting control by putting a definite minimum limit on the field excitation of the motor.

(c5) A temporarily and conditionally effective source of grid voltage for the grid circuit of the field rectifier may also be seen in the resistor 178. This low ohmic resistor is connected in series with a similar resistor 192 (15 ohms) across the motor armature 7 when contacts 17 and 18 of contactor F are closed. The resistors 178 and 192 act as dynamic braking resistors when the motor decelerates after contactor F is caused to drop out of actuation of the stop contact 36. If this happens when the driven reel core is nearly empty and the motor running at a correspondingly fast speed, the dynamic braking performance, ordinarily, would be poor. However, the voltage drop then produced across the resistor 178 is effective in the field rectifier grid circuit to bias the rectifier tubes to full conductance thus strengthening the motor field for securing a quick braking action.

Referring now to the functioning of the system as a whole, it will be understood from the foregoing that with a proper choice and arrangement of the circuit components, as above exemplified, the armature rectifier and appertaining control means operate to maintain constant armature voltage over a given range of motor speeds or a given range of reel build-up, while the field rectifier and appertaining control means are simultaneously operative to regulate the motor for maintenance of constant armature current. Thus, during the reeling operation of the drive motor and within the just-mentioned range of speeds, the motor is controlled to deliver constant horespower to the driven reel. As a result, the revolving speed of the motor and reel varies as the reel diameter increases (or decreases) so as to maintain substantially constant winding tension in the material being wound. The range of speeds over which such a constant horsepower and constant tension operation is accurately effective in the above-described system is about 4 to 1, corresponding to a reel build-up ratio of 4 to 1. However, the system affords a much larger total speed range of satisfactory winding operation by virtue of the feature referred to presently.

The tap point of potentiometer rheostat 182 of the field control means whose position or selected setting determines the value of the winding tension to be regulated is correlated to the tap point position or potentiometric rating of the rheostat 63 of the armature current limit control means so that the armature current value at which the current limiting action (of resistor 83, tube 102, tube 106) begins is only slightly above the value of armature current for which the field voltage regulating means are set (at rheostat 182) to regulate the field voltage for constant tension operation during the constant horespower range of motor operation. More specifically, the setting of rheostat 63 is such that the current limiting control for the armature circuit is responsive to a critical armature current value just high enough to keep the limiting control inactive during the entire constant horsepower operation of the drive, i. e., up to the point of operation when the field circuit receives full excitation from the field rectifier through the then fully conductive field rectifier; but this critical current value is below the load limit value of the current limit control means that in the conventional control systems serve to prevent overloads damaging to the rectifier tubes. Consequently, when in a system according to the invention the reel of material has built up under constant tension up to the diameter at which the field circuit reaches maximum excitation, any further increase in reel diameter results in the slight increase of armature current necessary to bring the current limit control for the armature circuit into play. This increase, due to the low amount of the critical current response value, is too small to impose an appreciable increase in tension on the material, so that the transition from voltage-responsive to current-responsive regulation of the armature voltage has no detrimental or rather hardly a noticeable effect on the condition of the material being wound. As soon as the current limit control becomes effective, it controls the armature voltage to hold the armature current constant during the further winding operation. Since then the field circuit receives constant excitation, the torque of the motor will remain constant throughout the remainder of the reel build-up, and the tension in the material will now slightly decrease roughly proportionately to the amount of buid-up.

This automatic changeover from constant horsepower to constant torque operation of the drive results in an extension of the reel build-up from the above-mentioned range of about 4 to 1, for instance, up to 6 to 1, or 8 to 1 depending upon how much decrease in tension a particular application will allow.

The performance just explained requires setting the armature current limit control (rheostat 63) in dependence upon the tension setting of the field voltage control (rheostat 182). Therefore, the rheostat 63 of the armature current limit control is preferably ganged up with the tension setting rheostat 182. In the illustrated embodiment these two rheostats are designed as a tandam potentiometer, the respective sliders being mechanically interconnected as shown by the broken-line connection 200 to move in a fixed relation to each other. Consequently, the current limit setting of the field voltage control is adjusted or changed as a function of the tension setting of the armature voltage control. Consequently, no matter how the tension setting is adjusted or changed, a winding operation (at increasing reel diameter) will first occur under constant tension up to full field excitation and will thereafter continue at a constant torque whose value is always pre-set by the correlated adjustment of the rheostat **63** to bring the current limiting control of the armature rectifiers into play after a very small rise in armature current.

This performance is not only of value for regularly operating with an increased reel build-up ratio, but is also desirable for constant tension winder drives where there is the possibility that the reel build-up will occasionally exceed the design limits. While ordinarily in constant tension drives, the value of armature current greatly increases as soon as the motor field is fully excited so that, when the rated build-up is exceeded, the strip or sheet material is apt to break due to excessive tension, the described automatic changes in current limit adjustment as a function of the tension setting prevents such damage because the tension increases only very slightly when the reel builds up beyond the full field condition and, shortly thereafter, the tension decreases and goes below the previously obtaining constant tension value.

While in the foregoing, I have described a specific embodiment of the invention, it is obvious that the invention permits of many and diversified changes and modifications as regards component circuits, circuit elements and other details. For instance, current limit devices, tube grid circuits, transformer circuits or current supplying other than those exemplified are readily applicable as well as other rectifier and amplifier means such as magnetic amplifiers with saturation-controllable reactors and series connected two-electrode rectifiers of any suitable type. I refrain from illustrating and specifically describing such further embodiments because the then required additional descriptions of considerable length would not add to the presentation or understanding of the essential features of the invention, it being obvious to those skilled in the art that the mentioned and other available modifications and changes can readily be made without foregoing the objects and advantages of the invention and without departing from its essential features set forth in the claims annexed hereto.

I claim as my invention:

1. A system for operating a core-type reel drive by rectified current from an alternating-current supply, comprising a motor armature circuit and a motor field circuit, alternating-current supply means, a controllable armature rectifier connecting said armature circuit to said supply means for providing rectified armature voltage, a controllable field rectifier connecting said field circuit with said supply means for providing rectified field voltage, said field rectifier having a control circuit, said control circuit having a current-responsive voltage source means connected with said armature circuit for controlling said field rectifier to maintain the current in said armature circuit at a constant value within a given speed range, said armature rectifier having a control circuit, said latter control circuit having a voltage-responsive voltage source means connected across said armature circuit for controlling said armature rectifier to maintain said armature voltage constant within said speed range, and current-control means connected with said armature circuit and responsive to a predetermined minimum value of said current below overload conditions of said current but higher than said constant current value, said limit control means being connected with said armature rectifier control circuit for causing it to control said armature rectifier to reduce said armature voltage in response to said predetermined value.

2. A system for operating a core-type reel drive by rectified current from an alternating-current supply, comprising a motor armature circuit and a motor field circuit, alternating-current supply means, a controllable armature rectifier connecting said armature circuit to said supply means for providing rectified armature voltage, a controllable field rectifier connecting said field circuit with said supply means for providing rectified field voltage, said field rectifier having a control circuit, said control circuit having a current-responsive voltage source means connected with said armature circuit for controlling said field rectifier to maintain the current in said armature circuit at a constant value within a given speed range, said armature rectifier having a control circuit, said latter control circuit having a voltage-responsive voltage source means connected across said armature circuit for controlling said armature rectifier to maintain said armature voltage constant within said speed range, and current limit control means having a circuit member connected with said armature circuit to provide a limit control voltage substantially proportional to the current in said armature circuit and having a normally inactive trigger device with a trigger circuit to said member, said device being responsive to a given minimum value of said limit control voltage corresponding to a predetermined value of said current below overload conditions of said current but higher than said constant current value and having an output circuit connected with said armature rectifier control circuit for causing it to control said armature rectifier to reduce said armature voltage in response to said given voltage value.

3. A system for operating a core-type reel drive by rectified current from an alternating-current supply, comprising a motor armature circuit and a motor field circuit, alternating-current supply means, a controllable armature rectifier connecting said armature circuit to said supply means for providing rectified armature voltage, a controllable field rectifier connecting said field circuit with said supply means for providing rectified field voltage, said rectifiers having respective control circuits for controlling said armature voltage and field voltage respectively, current-responsive voltage source means connected with said armature circuit to provide a control voltage dependent upon the current in said armature circuit and having adjustable potentiometric resistance means connected with said field rectifier control circuit for causing it to control said field rectifier to maintain over a given speed range said current at a constant value determined by the adjustment of said resistance means, said armature rectifier control circuit having a voltage-responsive circuit member connected across said armature circuit for controlling said armature rectifier to maintain said armature voltage constant over said speed range, and current limit control means having an adjustable resistance circuit connected with said armature circuit and responsive to the current in said armature circuit to provide a limit control voltage varying in accordance with said current, said current limit control means having a trigger relay circuit connected between said resist-

ance circuit and said armature rectifier control circuit for controlling the latter to control said armature rectifier to reduce said armature voltage when said limit control voltage exceeds a value dependent upon the adjustment of said resistance circuit, said resistance circuit having an adjustment related to that of said adjustable potentiometric resistance means so that said limit control voltage value corresponds to a value of said current below overload conditions of said current but higher than said constant current value, and said resistance circuit and said resistance means having respective adjusting means connected with each other to set said limit control voltage value as a function of the adjustment of said resistance means.

4. A system for operating a core-type reel drive by rectified current from an alternating-current supply, comprising a motor armature circuit and a motor field circuit, alternating-current supply means, a controllable armature rectifier connecting said armature circuit to said supply means for providing said armature circuit with rectified armature voltage and having rectifier control means for controlling said armature voltage, a controllable field rectifier connecting said field circuit with said supply means for providing said field circuit with rectified field voltage and having rectifier control means for controlling said field voltage, said armature rectifier control means having a control circuit comprising two series opposed sources of component control voltages, one of said sources being connected across said armature circuit to provide a voltage dependent upon said armature voltage and said other source being speed-responsive and having a variable voltage for controlling said armature rectifier to maintain said armature voltage at a value depending upon said variable voltage. said field rectifier control means having a control circuit comprising two series-opposed sources of component control voltages, one of said latter two sources being connected with said armature circuit and responsive to the current in said armature circuit, and said remaining source having constant voltage and having adjusting means for setting said latter voltage in accordance with a desired tension in the reeling material for controlling said field rectifier to maintain said current constant at a value set by said adjusting means, current-responsive voltage supply means connected with said armature circuit to provide a current limit control voltage in response to occurrence of a predetermined value of said current below overload conditions of said current but higher than said constant current value, said voltage supply means having an adjustable circuit member for adjusting said predetermined value and being connected with said armature rectifier control circuit for causing said current limit control voltage to control said armature rectifier to reduce said armature voltage, and connecting means joining said adjusting means with said adjustable circiut member for setting said predetermined current value as a function of the desired tension set by said adjusting means.

5. A system for operating a core-type reel drive, comprising a motor armature circuit and a motor field circuit, controllable field-voltage supply means connected with said field circuit and having a control circuit, said control circuit having current-responsive circuit means connected with said armature circuit and responsive to the current in said armature circuit for regulating the voltage of said field circuit to maintain said current at a constant value over a first range of drive speeds corresponding to the range between minimum and maximum values of said field voltage, controllable armature voltage supply means connected to said armature circuit and having another control circuit, said other control circuit having voltage responsive circuit means connected with said armature circuit for regulating the voltage of said armature circuit to remain constant, and current-limit control means connected with said armature circuit and being responsive to a current limit value below overload conditions of said current and above said constant current value so as to respond after said field voltage has reached said maximum value, said current-limit control means being connected with said other control circuit for regulating the current of said armature circuit to remain constant at said limit value over a second range of drive speed below and adjacent to said first range.

6. A system for controlling a core-type reel drive to operate at constant horsepower over a range of high speeds and at constant torque over an adjoining range of low speeds, comprising a motor armature circuit and a motor field circuit, controllable field-voltage supply means connected with said field circuit and having a control circuit, current-responsive voltage supply means connected with said armature circuit and having voltage adjusting means connected with said control circuit for controlling the field voltage of said field circuit to maintain the current in said armature circuit over said high speed range at a constant value adjusted by said adjusting means, controllable armature voltage supply means connected to said armature circuit and having another control circuit, said other control circuit having voltage responsive circuit means connected with said armature circuit for regulating the voltage of said armature circuit to remain constant over said high speed range, current-limit control means connected with said armature circuit and responsive to a predetermined minimum value of said current, said limit control means having an adjustable circuit member for adjusting said minimum value and being connected with said other control circuit for controlling said armature voltage supply means to maintain said current constant over said low speed range, said circuit member and said adjusting means being correlated and interconnected for joint adjustment so that said minimum value is above said constant value and below overload values of said current for different adjustments of said voltage adjusting means.

7. A system for operating a core-type reel drive by rectified current from an alternating-current supply, comprising a motor armature circuit and a motor field circuit, alternating-current supply means, a controllable armature rectifier connecting said armature circuit to said supply means for providing rectified armature voltage, a controllable field rectifier connecting said field circuit with said supply means for providing rectified field voltage, said rectifier having respective control circuits, current transformer means having primary windings connected in said armature circuit and having secondary windings to provide respective output voltages proportional to the current in said armature circuit, circuit means connecting one of said secondary windings with said field rectifier control circuit for controlling said field rectifier by the respective one of said

output voltages to regulate said field voltage for a constant value of said current, voltage-responsive source means connected across said armature circuit and connected with said armature rectifier control circuit for controlling said armature rectifier to maintain said armature voltage at a constant value, and current-limit control means connected between said other secondary winding and said armature rectifier control circuit and responsive to a limit value of said current above said constant value and below overload conditions of said current for causing said armature rectifier to regulate said armature voltage for maintaining said current at said limit value when said field voltage has reached its full field value.

8. In a system according to claim 7, said circuit means comprising an adjustable source of constant voltage series opposed to said one output voltage for setting said constant value of said current in accordance with a desired winding tension, and voltage supply means having an adjustable potentiometric resistance member connected with said voltage-responsive source means in series opposed relation thereto whereby said constant value of armature voltage depends upon the adjustment of said resistance member.

9. In a system according to claim 8, said current limit control means having an adjustable potentiometric resistance member connecting said other secondary winding with said armature rectifier control circuit, said two potentiometric resistance members being interconnected for joint adjustment so that said limit value of current varies in dependence upon changes in tension adjustment.

10. A control system for a direct current motor having an armature winding and a field winding comprising, an armature voltage regulator adapted for connection to said armature winding to respond to the voltage and current thereof, a field excitation regulator adapted for connection to said armature winding to respond to the current thereof, an adjustable impedance device in said armature voltage regulator for controlling said armature voltage regulator, an adjustable impedance device in said field excitation regulator for controlling said field excitation regulator, and means for simultaneously adjusting said impedance devices.

11. A control system comprising, a direct current motor having an armature winding and a field winding, an armature voltage regulator responsive to the voltage and current of said armature winding for energizing said armature winding, a field excitation regulator responsive to the current of said armature winding for controlling the excitation of said field winding, adjustable control means connected with said armature voltage regulator for varying the sensitivity thereof to armature winding current, adjustable control means connected with said field excitation regulator for controlling the operation thereof, means for simultaneously adjusting both of said control means.

12. A control system for a direct current motor having an armature winding and a field winding comprising, an armature voltage regulator adapted for connection to said armature winding to respond to the voltage and current thereof, a field excitation regulator adapted for connection to said armature winding to respond to the current thereof, an adjustable impedance device in said armature voltage regulator for controlling said armature voltage regulator, an adjustable impedance device in said field excitation regulator for controlling said field excitation regulator, and means for adjusting one impedance device in dependence of adjustment of the other impedance device.

13. A control system comprising a direct current motor having an armature winding and a field winding, an armature voltage regulator responsive to the voltage and current of said armature winding for energizing said armature winding, a field excitation regulator responsive to the current of said armature winding for controlling the excitation of said field winding, adjustable control means connected with said armature voltage regulator for varying the sensitivity thereof to armature winding current, adjustable control means connected with said field excitation regulator for controlling the operation thereof, and means for adjusting one control means in dependence of adjustment of the other.

14. In a control for a direct current motor having an armature and a field winding comprising, an armature current responsive field winding excitation regulator for controlling excitation of said field winding to maintain substantially constant armature current, adjustable control means forming a part of said field winding excitation regulator for applying an adjustable control thereto, an armature voltage and armature current responsive armature voltage regulator for energizing said armature winding to maintain substantially constant armature voltage, adjustable control means forming a part of said armature voltage regulator for varying the sensitivity thereof to armature current, and means for adjusting said last-named control means in dependence of adjustment of said first-named control means.

FLETCHER E. McLANE.

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