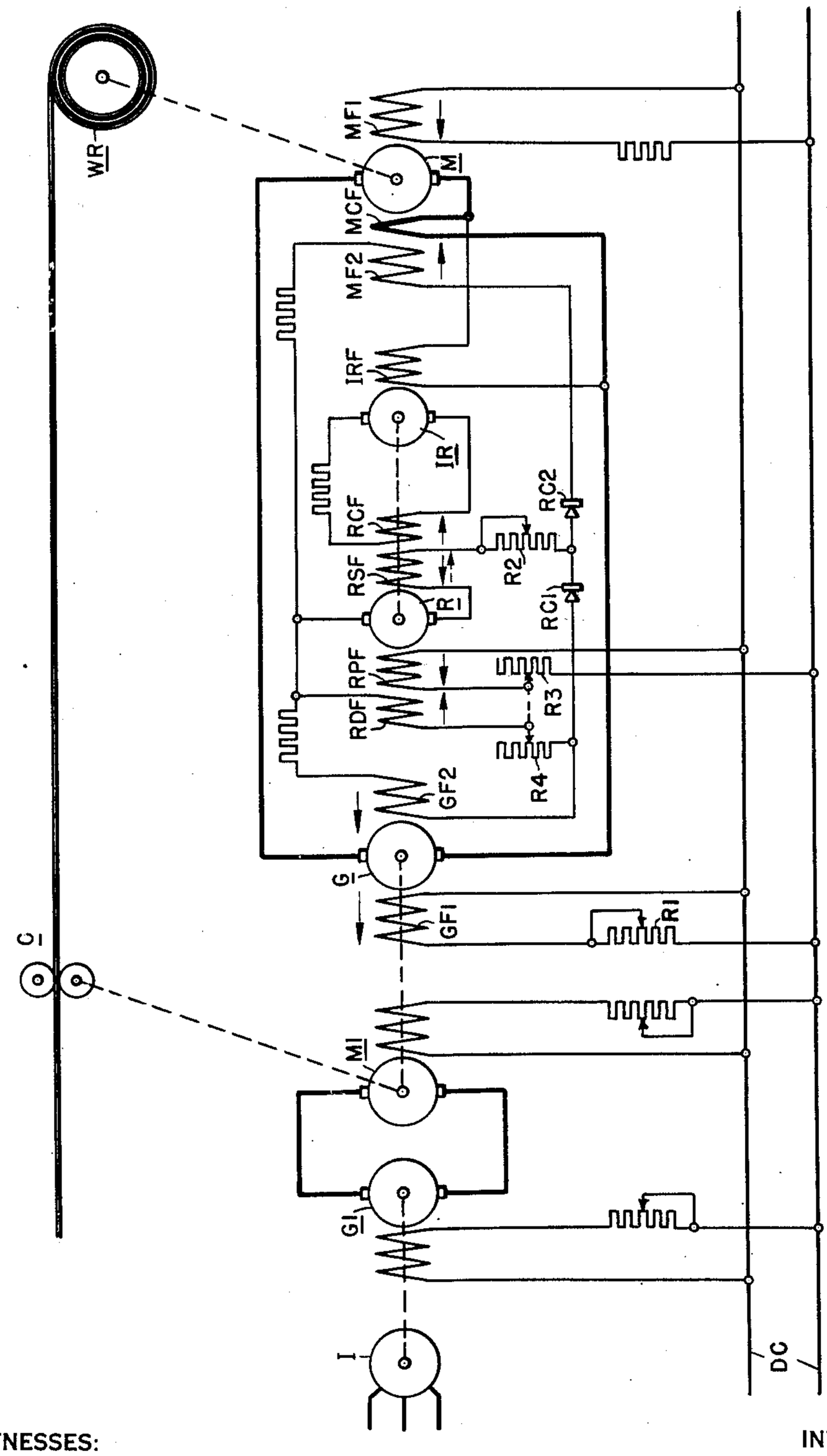
Feb. 24, 1953

R. E. PABST

2,629,845

ELECTRICAL APPARATUS

Filed Dec. 22, 1949



WITNESSES:

E. A. McKelvey.

E. F. Oberheim.

INVENTOR

Richard E. Pabst.

BY

Paul C. Friedemann

ATTORNEY

Patented Feb. 24, 1953

2,629,845

UNITED STATES PATENT OFFICE

2,629,845

ELECTRICAL APPARATUS

Richard E. Pabst, San Antonio, Tex., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application December 22, 1949, Serial No. 134,460

15 Claims. (Cl. 318—144)

1

This invention relates generally to electric drives, and more in particular to an electric drive for controlling the operation of a windup reel used for winding up the paper coming off a paper mill.

In paper mill drives it is frequently necessary especially in the unreeling and reeling operations required, to provide wide speed ranges of operation for the motors controlling the winding and unwinding reels. In the usual case a speed range of about 6:1 may be obtained from a conventional direct-current motor by means of field control. When the field is at its full strength the motor is operating at its minimum speed, and when the field is at minimum strength the motor is operating at maximum speed. Variations in speed are also obtainable by armature current variations, and frequently the motor speed is controlled by utilizing both field control and armature current, or voltage control, to obtain the speed characteristics and speed range which are required. In many cases it is desired on a paper mill drive, in both the unwinding and windup reels, to provide a reel core of some 4 inches in diameter on which the paper is to be wound, the finished diameter being of the order of 48 inches, representing a diameter ratio between the full reel and empty reel of about 12:1, indicating a motor speed range of 12:1.

In addition to the above-noted problems concerning the desirability of wide speed range control for the motor, it is additionally necessary that the paper tension be maintained substantially constant in order to prevent overstressing of the paper due to too much tension and possible breakage thereof, and undertensioning of the paper which results in the paper being loosely wound on the reel. In practice, it has been found convenient to utilize the variation in armature current of the motor as the cue for controlling the motor. While armature current variations are not a precise indication of the strip or paper tension, it has been found sufficiently close for practical purposes.

Accordingly, it is a principal object of this invention to provide an electric drive of the character referred to which affords a wide speed range of control for the motor.

More specifically, it is an object of this invention to provide a control for a motor to obtain a wide range of motor speeds in which both motor field excitation control and armature voltage control are utilized to control the motor speed.

It is also an object of this invention to provide

2

a drive for a windup reel on a paper mill which maintains substantially constant paper tension over a wide range of speeds.

More specifically, it is an object of this invention to provide an electrical regulating system embodying a control unit capable of maintaining an electrical output independently of external control.

The foregoing statements are merely illustrative of the various aims and objects of this invention. Other objects and advantages will become apparent upon a study of the following descriptive disclosure when considered in conjunction with the accompanying drawing, in which the single figure diagrammatically illustrates an electrical control system for a motor utilized to drive the windup reel of a paper mill.

The paper mill in the drawing is only fragmentarily illustrated, the final set of calender rolls C being shown and the paper strip terminating in a windup reel designated WR. The means for driving the calender roll C is represented in a direct-current motor M1, the armature of which is connected in series with the armature of a generator G1 to be energized thereby. Each of the motor and generator is provided with field windings which are energized from a source of direct current designated DC. The particular manner in which the excitation is controlled in order to obtain constant operating speed is not illustrated in the interest of simplicity, since per se such equipment forms no part of this invention. The generator G1 is driven by a suitable induction motor designated I.

The drive for the wind-up reel WR includes a direct-current motor M, the rotor of which is mechanically coupled through suitable gearing (not shown) to the shaft of the windup reel. Motor M is provided with a series-connected interpole field winding designated MCF and is connected in series with a main generator G to be energized thereby. The generator is driven through a suitable mechanical connection with the motor M1 which drives the calender rolls. Thus this generator is driven at a speed proportional to the speed of the calender rolls and with constant excitation of a predetermined degree determined by the setting of the rheostat R1 in the circuit of the field GF1 which is energized across the DC supply, the output of the generator G will be a function of its speed of operation. Accordingly, assuming constant excitation of the motor field MF1 which is also energized across the source DC, the speed of the motor M will be

controlled by armature voltage variations, and will accordingly tend to be proportional to the speed of operation of the calender rolls C. As a rule the calender C, once the machine is in operation, will be operated at substantially constant speed. However, for the purpose of threading the paper through the roll stands, it is necessary that these rolls be operated at a fairly low speed, and such speeds are obtained as a rule by properly controlling the excitation of the generator G1, and ordinarily are such as to afford a paper velocity through the stands of about 50 feet per minute. During such operation of the mill, the motor M must be operated at a correspondingly low speed, and once the threading operation is completed and the paper properly secured on the windup reel to be wound thereon, the speed of the mill is stepped up, and speeds as high as 2,000 feet per minute are contemplated requiring extremely accurate speed control of the windup reel to maintain the degree of tension required in the paper.

The control according to this invention which accomplishes this objective embodies a regulating generator generally designated R. This regulating generator when used in regulating systems affords cerain advantages which are not realizable with conventional exciters. This generator is of the self-energizing type and its load circuit is so adjusted by means, for example, of an adjustable resistor R2, which in the instant application is connected in series with the armature circuit, that the line of the load circuit is tangent to the initial straight line portion of the no-load saturation curve. This generator to be self-energizing is provided with a series field winding designated RSF and is capable of producing an electrical output upon rotation thereof due to the residual flux independent of external excitation. The output may therefore be anywhere along the tangent curves of one polarity or the reverse, depending on the direction of rotation with respect to the residual flux. While not shown in the drawing in the interest of simplicity, this generator forms part of a small motor-generator set, and in the instant application is intended to be driven at a constant speed. Thus in order to control the output of this generator, certain intelligences are applied thereto in the form of excitation provided by a plurality of control field windings which are selectively excited from different points in the system in order to obtain the type of output which is desired to regulate the motor M through the main generator G so that its horsepower output will be substantially constant.

Accordingly, the field system of this generator includes a main field winding RPF which may be identified as the pattern field winding. This field winding is excited from the direct-current source DC through a series-connected rheostat R3 which is adjusted to provide the required magnitude of current for the main excitation of the regulating generator. A current field winding RCF responsive to the motor armature current is differentially related to the pattern field winding RPF as shown by the arrows adjacent the respective windings. This current field is excited by means of a generator IR which in turn is excited by a field IRF connected across the interpole winding MCF of the motor to respond to the voltage thereacross. The voltage of this interpole field winding, it will be appreciated, is proportional to the motor armature current, since

the armature current flows therethrough. The final field winding for the regulating generator is designated RDF and is also differentially related to the pattern field winding RPF as shown by the arrows adjacent the respective windings. This field winding is energized in dependence of the voltage drop across the generator field winding GF2 which in turn is excited by the regulating generator. In accomplishing this, the terminals of the field winding GF2 are connected across the armature circuit of the regulating generator in a circuit including a rectifier RC1. The differential field winding RDF is connected across the generator field winding GF2 in a circuit which includes a rheostat R4 which is mechanically ganged with the rheostat R3 so that adjustments of the pattern field winding excitation by means of the rheostat R3 will simultaneously vary the excitation of the differential field winding RDF to maintain the desired proportionality of the differential excitation of this differential field with respect to the pattern field RPF.

The motor M is provided with an additional field winding designated MF2 which is cumulatively related to the main field winding for the motor MF1. This field winding is connected across the armature circuit of the regulating generator in parallel with the generator field GF2 in a circuit which includes a rectifier RC2.

The generator field winding GF2 for the polarity of excitation afforded by the rectifier RC1 is cumulatively related to the main generator field winding GF1. Thus the field GF2 when excited adds its excitation to that of the generator field GF1 to increase the output of the generator, and when the polarity of the output voltage of the regulating generator reverses, this field is no longer excited, because the excitation voltage is applied in opposition to the rectifier RC1 which therefore blocks a current flow through the field GF2.

The motor field MF2 which is cumulative with respect to the motor field MF1 is prevented from being excited by that polarity of voltage which excites the generator field GF2 because the rectifier RC2 in series in this motor field circuit is in oppositon to the current flow, but upon a reversal in the polarity of output of the regulating generator current flow through the rectifier RC2, and the field MF2 is excited adding its ampere turns to those of the main field and further reducing the speed of the motor below that afforded by armature voltage control alone.

The regulating generator is controlled by its fields as follows: The output of the regulating generator upon rotation thereof and upon the application of the pattern field winding excitation tends to increase in the direction urged by the pattern field excitation. The series field excitation for this condition is indicated by the solid arrow adjacent thereto. The ampere turns of the two differential field windings RCF and RDF subtracts from those of the pattern field winding, and these fields are so designed that for a predetermined degree of exciting current their ampere turns will be equal and opposite to those of the pattern field windng, at which time the total external excitation of the machine is zero. If the machine tends to increase its output beyond the condition at which the pattern and differential fields are balanced, the differential excitation will be increased due to changes in the electrical conditions in the system to which these fields are responsive. As a

result of the increase in the differential excitation, the machine is excited in an opposite sense tending to reduce its output to that which is required for proper control of the system. On the other hand, if the output for any reason is insufficient, or for any reason tends to fall below that required for an instant condition in the system, the electrical conditions of the system reflected in a dropping differential excitation of the machine results in a net excitation in favor of the pattern field tending to urge the output of the generator upwardly, at which time the increasing differential excitation due to the progressively changing electrical conditions in the system again reduces the net external excitation to zero. It will therefore be appreciated that the function of the pattern and differential fields of the generator is that of urging the output of the generator in the proper direction and to the proper magnitude, at which time the effect of these fields is balanced or reduced to zero and the generator, due to its self-energizing properties, maintains its electrical output until a change in the conditions in the system requires a different output.

This invention will be better understood from a consideration of the operation of this system. Inasmuch as the function of the invention during threading operation is similar in some respects to that for a continuous windup operation, insofar as the indication for correction of system errors is concerned, the following description will be confined to a constant paper speed reeling operation. Assuming that the paper mill is operating at normal speed, the main generator G will produce an electrical output which is proportional to the speed at which the paper is passing through the calendar rolls. This voltage, which is applied to the armature of the reel motor M which is constantly excited by its field MF1, results in a motor speed which is proportional to the paper speed. However, with each revolution of the wind-up reel, the reel diameter is increased by the thickness of the material being wound thereon. Therefore, the reel radius is increasing and the revolutions per minute must be reduced in order to maintain a constant peripheral velocity corresponding to the linear speed of the paper. As the reel diameter increases the motor tends to slow down due to the increasing torque loading. As a consequence for a given degree of excitation of the main motor the armature current will tend to increase due to the fact that the back EMF of the motor is decreasing. As the armature current increases the excitation of the regulating generator control field RCF also tends to increase.

Assuming further that the windup operation has just begun, the polarity of output of the regulating generator is now such that current flows through the field GF2 since the polarity of this voltage is such that the rectifier RC1 will pass current. The polarity of the series field RSF for this condition is indicated by the solid arrow. Thus the field RDF of the regulating generator is energized by the voltage across the generator field GF2, and at this instant its ampere turns added to those of the field RCF are momentarily balanced against those of the pattern field RPF, but the armature current is increasing in this assumption, and therefore the differential excitation is increasing and predominates that due to the pattern field RPF. As a consequence, the output voltage of the regulating generator is decreased reducing the excitation of the field GF2, and correspondingly reducing the output voltage of the main generator to tend to reduce the motor speed. This results in a drop in the excitation of the differential field RDF and the differential and pattern field excitation again tends to approach equilibrium when the regulating generator output corresponds to that which is required by the system. Thus it will be appreciated that the output of the regulating generator from that value which affords excitation of the field GF2 to give maximum speed is progressively reduced and the system is arranged so that for a given diameter of the reel the regulating generator's output will be reduced to zero, and consequently the field GF2 will no longer contribute excitation to the generator G. The speed control range is now further varied in response to further changes in reel diameter and motor armature current by increasing the total excitation of the motor M. Further increases in armature current again increase the differential excitation which now drives the regulating generator through zero output and causes it to build up its output in the reverse direction. The polarity of the series field RSF is now reversed as indicated by the dotted arrow. This reverse output voltage is now blocked by the rectifier RC1 and the generator field GF2 is therefore not excited and likewise field RDF of the regulating generator is not excited. But the polarity of this reversed voltage is such that the current thereof is passed by the rectifier RC2 energizing the motor field MF2 which adds its excitation to that of the field MF1 strengthening the motor field and further reducing the speed thereof. This operation continues as described until the maximum reel diameter has been reached.

In a practical example upon completion of the threading operation the supercalender roll system is brought up to operating speed and the reel motor operates at maximum speed, as determined by minimum reel diameter. At this point in the windup operation the main generator voltage is approximately twice in value that which would be given by the constant value main generator field GF1. The additional excitation to obtain this double voltage is supplied by the generator auxiliary field GF2 through its blocking rectifier RC1. The value of regulating generator voltage needed to provide the required excitation of field GF2 is obtained by the resultant interaction of the regulating generator fields RPF, RCF and RDF. For this condition of maximum speed, field RDF is so proportioned that when added to RCF the sum of the differential ampere turns equals those of RPF. The regulating generator voltage therefore builds up in the direction urged by pattern field RPF until the control excitation reaches zero with rectifier RC2 preventing motor field MF2 being differential with respect to MF1. The value of motor current at maximum speed which corresponds to minimum reel diameter will be approximately one-half the constant value over the slow speed range. As the reel builds up in diameter, the motor speed decreases as hereinabove noted with an increase in motor current resulting in an increase in the excitation of the differential current field of the regulating generator, reducing this generator's output which in turn decreases the main voltage. As the speed decreases it will be appreciated that the motor current continues to increase until the regulating generator voltage is zero and the main generator voltage is

roughly one-half the initial value. The speed range of adjustment afforded by armature voltage control is approximately 2:1, and during this control the motor current will increase linearly from 50% to 100%, while the main generator voltage decreases from 200% to 100% giving a resulting horsepower over the speed range which will vary from the desired value at maximum speed to approximately 112½% of that value at 75% speed and back to 100% at about one-half speed. From one-half speed down to minimum speed the control of this invention will function with the regulating generator exciting the field MF2 cumulatively with respect to MF1, while the blocking rectifier RC1 prevents any further effect from the differential field RDF of the regulating generator and the field GF2 of the main generator.

The adjustment afforded by the rheostat R3 in series with the regulating generator pattern field RPF provides for the recalibration of paper tension. When tension is recalibrated by adjustment of the pattern field, the mechanical connection between rheostats R3 and R4 automatically recalibrates the field RDF to maintain a fixed ratio of excitation between these fields.

When the speed of the paper is changed by changing the speed of the motor M1, the main generator voltage which is linear with the generator speed will correspondingly change and result in the required motor speed. The paper tension under this condition will remain the same since it is determined by the motor current and the regulating generator control which is unchanged in this change of paper speed. The main generator field GF1 remains unchanged. Thus the relation between the fields GF2 and GF1 will remain unchanged by the various speed ranges of the calender rolls afforded by adjustment of the speed of motor M1.

While but one embodiment of this invention has been herein illustrated and described, it will be appreciated by those skilled in the art that numerous variations in control details may be obtained without departing from the spirit and scope of the teachings of this invention. Accordingly, it is intended that the foregoing disclosure shall be considered only as illustrative and not interpreted in a limiting sense.

I claim as my invention:

1. In an electric drive for controlling the speed of a motor over a wide speed range, the combination of, a motor having a pair of cumulatively related field windings, a main generator having a pair of cumulative field windings, circuit means for applying a predetermined degree of excitation to one motor field winding, circuit means for applying a predetermined degree of excitation to one generator field winding, circuit means connecting said main generator to said motor to energize said motor, a regulating generator, excitation circuit means for applying a predetermined degree of excitation to said regulating generator, circuit means including a series-connected rectifier connecting said regulating generator to the other generator field winding to excite said other generator field winding cumulatively with respect to said one generator field winding, circuit means including a series-connected rectifier for connecting said regulating generator to the other motor field winding to excite said other motor field winding cumulatively with respect to said one motor field winding and to prevent excitation of said other motor field winding for the polarity of voltage output of said regulating generator used to excite said other generator field winding, and circuit means responsive to the current supplied to said motor for exciting said regulating generator differentially with respect to said excitation circuit means.

2. In an electric drive for controlling the speed of a motor over a wide speed range, the combination of, a motor having a pair of cumulatively related field windings, a main generator having a pair of cumulative field windings, circuit means for applying a predetermined degree of excitation to one motor field winding, circuit means for applying a predetermined degree of excitation to one generator field winding, circuit means connecting said main generator to said motor to energize said motor, a regulating generator, excitation circuit means for applying a predetermined degree of excitation to said regulating generator, circuit means including a series-connected rectifier connecting said regulating generator to the other generator field winding to excite said other generator field winding cumulatively with respect to said one generator field winding, circuit means including a series-connected rectifier for connecting said regulating generator to the other motor field winding to excite said other motor field winding cumulatively with respect to said one motor field winding and to prevent excitation of said other motor field winding for the polarity of voltage output of said regulating generator used to excite said other generator field winding, circuit means responsive to the current supplied to said motor for exciting said regulating generator differentially with respect to said excitation circuit means, and circuit means responsive to the voltage of said other generator field winding for further differentially exciting said regulating generator.

3. In an electric drive for controlling the speed of a motor over a wide speed range, the combination of, a main generator for energizing the motor, circuit means for applying a predetermined degree of excitation to said main generator, circuit means for applying a predetermined degree of excitation to said motor, a regulating generator, circuit means responsive to the output of said regulating generator for cumulatively exciting said main generator for one polarity of said output and for preventing said last-named excitation of said main generator for an opposite polarity output of said regulating generator, circuit means responsive to the output of said regulating generator for cumulatively exciting said motor in dependence of said opposite polarity output and for preventing said cumulative excitation of said motor during said one polarity of output of said regulating generator, and circuit means responsive to the current of said motor for controlling said regulating generator.

4. Apparatus as set forth in claim 3 in which said regulating generator is a self-energizing generator adjusted to operate on its air-gap line.

5. In an electric drive for controlling the speed of a motor having a pair of field windings, the combination of, a main generator having a pair of field windings, circuit means for connecting said main generator to said motor to energize said motor, circuit means for applying a predetermined degree of excitation to one field winding of said generator and one field winding of said motor, a regulating generator, circuit means responsive to motor current for controlling said regulating generator, circuit means responsive to one polarity of output of said regulating generator

for exciting the other field winding of said main generator, and circuit means responsive to a reversal in output of said regulating generator for exciting the other field winding of said motor.

6. In an electric drive for controlling the speed of a motor having a pair of field windings, the combination of, a main generator having a pair of field windings, circuit means for connecting said main generator to said motor to energize said motor, circuit means for applying a predetermined degree of excitation to one field winding of said generator and one field winding of said motor, a regulating generator, said regulating generator being a self-energizing generator adjusted to operate on its air-gap line, circuit means responsive to motor current for controlling said regulating generator, circuit means responsive to one polarity of output of said regulating generator for exciting the other field winding of said main generator, and circuit means responsive to a reversal in output of said regulating generator for exciting the other field winding of said motor.

7. In an electric drive for controlling the speed of a motor having a pair of field windings, the combination of, a main generator having a pair of field windings, circuit means for connecting said main generator to said motor to energize said motor, circuit means for applying a predetermined degree of excitation to one field winding of said generator and one field winding of said motor, a regulating generator, a main field winding and a differential field winding for the regulating generator, circuit means for applying predetermined excitation to said main field winding, circuit means responsive to motor current for exciting the differential field winding of the regulating generator, circuit means responsive to one polarity of output of said regulating generator for exciting the other field winding of said main generator, and circuit means responsive to a reversal in output of said regulating generator for exciting the other field winding of said motor.

8. In an electric drive for controlling the speed of a motor having a pair of cumulatively related field windings, the combination of, a generator having a pair of cumulatively related field windings and having circuit connections for connection to said motor to energize said motor, circuit connections for applying a predetermined degree of excitation to one field winding of said motor, circuit connections for applying a predetermined degree of excitation to one fiield winding of said generator, amplifier means having an output circuit, control means for said amplifier means for affording one polarity of output of said amplifier means, control means for said amplifier means responsive to an operating quantity of said motor for controlling said amplifier means to reverse the polarity of output thereof, circuit means connecting said output circuit with the other field winding of said generator for energizing said other field winding of said generator for one polarity of output of said amplifier means and preventing excitation of said other field winding of said generator upon a reversal in polarity of output of said amplifier means, and circuit means connecting said output circuit with the other field winding of said motor for preventing energization of said other field winding of said motor for said one polarity of output of said amplifier and for energizing said other field winding of said motor upon a reversal in polarity of output of said amplifier means.

9. In an electric drive for controlling the speed of a motor having a pair of cumulatively related field windings, the combination of, a generator having a pair of cumulatively related field windings and having circuit connections for connection to said motor to energize said motor, circuit connections for applying a predetermined degree of excitation to one field winding of said motor, circuit connections for applying a predetermined degree of excitation to one field winding of said generator, amplifier means having an output circuit, control means for said amplifier means for affording one polarity of output of said amplifier means, control means for said amplifier means responsive to an operating quantity of said motor for controlling said amplifier means to reverse the polarity of output thereof, circuit means connecting said output circuit with the other field winding of said generator for energizing said other field winding of said generator for one polarity of output of said amplifier means and preventing excitation of said other field winding of said generator upon a reversal in polarity of output of said amplifier means, circuit means connecting said output circuit with the other field winding of said motor for preventing energization of said other field winding of said motor for said one polarity of output of said amplifier and for energizing said other field winding of said motor upon a reversal in polarity of output of said amplifier means, and control means responsive to the voltage of said other field winding of said generator for additionally controlling said amplifier means to reverse the polarity of output thereof.

10. In a control for a motor-generator drive wherein the armature of the generator is electrically connected to the armature of the motor, the motor and the generator being separately excited and each having a control field winding, the combination of, amplifier means having an output circuit, control circuit means for controlling said amplifier means to produce one polarity of electrical output, control circuit means for connection with said motor to respond to an operating quantity thereof for controlling said amplifier means to reverse the polarity of output thereof, circuit connections including rectifier means for connecting the control field winding of the generator to said output circuit to energize said control field winding of said generator for said one polarity of output of said amplifier means, and circuit connections including rectifier means for connection to the control field winding of the motor for energizing the control field winding of the motor upon reversal of the polarity of output of said amplifier means.

11. Apparatus as recited in claim 10, wherein said amplifier means is a self-energizing generator having a load circuit resistance causing operation of the self-energizing generator on its air-gap line.

12. In a control for a motor-generator drive wherein the armature of the generator is electrically connected to the armature of the motor, the motor and the generator being separately excited and each having a control field winding, the combination of, amplifier means having an output circuit, control circuit means for controlling said amplifier means to produce one polarity of electrical output, control circuit means for connection with said motor to respond to an operating quantity thereof for controlling said amplifier means to reverse the polarity of output thereof, circuit connections including rectifier means for connecting the con-

trol field winding of the generator to said output circuit to energize said control field winding of said generator for said one polarity of output of said amplifier means, circuit connections including rectifier means for connection to the control field winding of the motor for energizing the control field winding of the motor upon reversal of the polarity of output of said amplifier means, and control circuit means for connection to the control field winding of the generator to respond to the voltage thereof for additionally controlling said amplifier means to reverse the polarity of output thereof.

13. Apparatus as recited in claim 12 in which said amplifier means is a self-energizing generator having a load circuit resistance causing operation of the self-energizing generator on its air-gap line.

14. In an electric drive for controlling the speed of a motor having a pair of field windings, the combination of, a main generator having a pair of field windings, circuit means for connecting said main generator to said motor to energize said motor, circuit means for applying a predetermined degree of excitation to one field winding of said generator and one field winding of said motor, a regulating generator, a main field winding and a pair of differential field windings each of which is differentially related to said

main field winding of said regulating generator, circuit means for applying predetermined excitation to said main field winding, circuit means responsive to motor current for exciting one differential field winding, circuit means responsive to one polarity of output of the regulating generator for exciting the other field winding of said main generator, circuit means responsive to a reversal in output of the regulating generator for exciting the other field winding of the motor, and circuit means connecting the other differential field winding of the regulating generator to said other field winding of said main generator to be energized in dependence of the voltage thereof.

15. Apparatus as recited in claim 14 and in addition, means for simultaneously varying the excitation of said main field winding and said other differential field winding of said regulating generator in the same sense.

RICHARD E. PABST.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,406,426	King	Aug. 27, 1946