March 12, 1957 W. R. HARDING ET AL 2,785,362

ADJUSTABLE VOLTAGE DRIVE

Filed Sept. 6, 1951 3 Sheets-Sheet 1

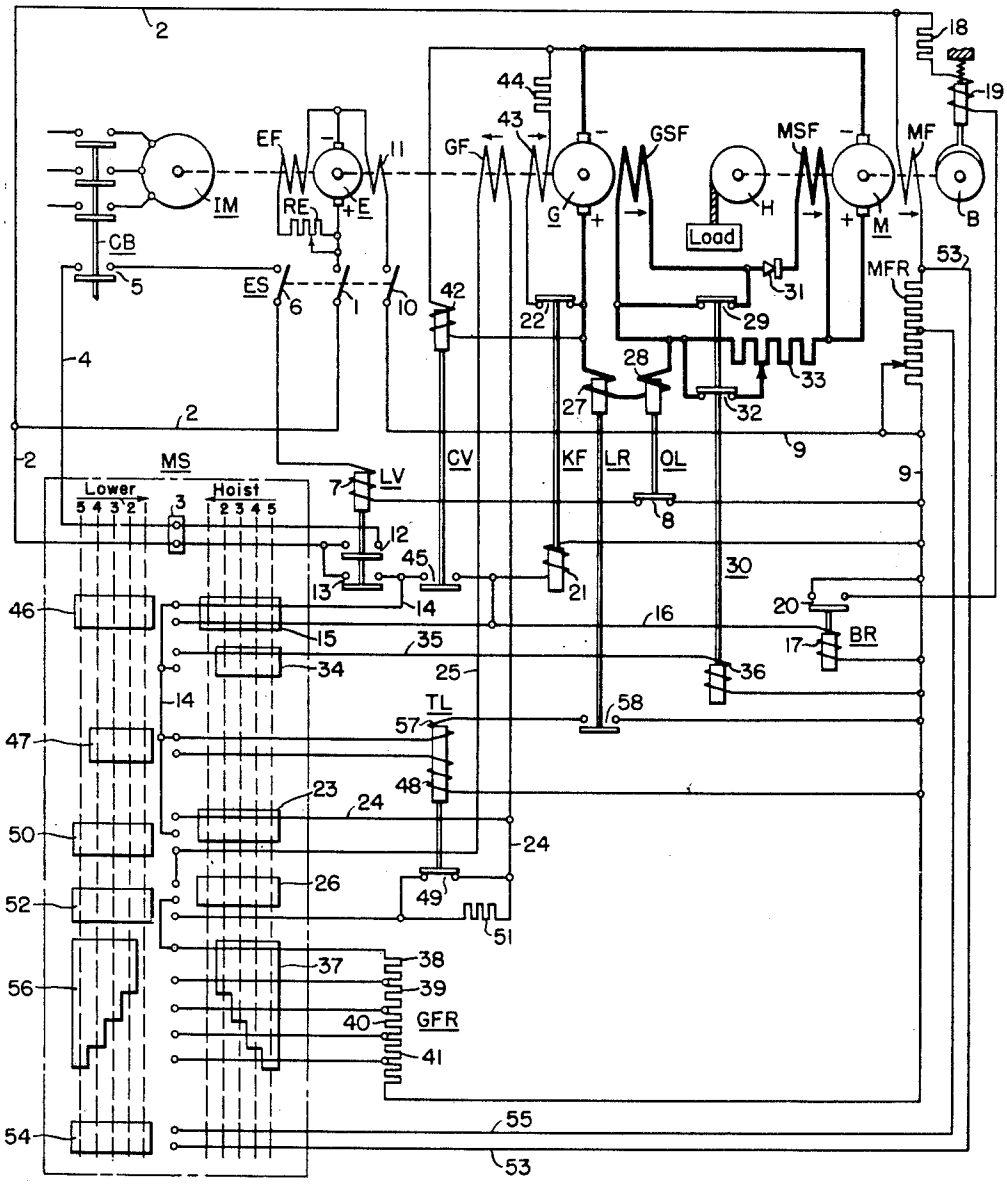

Fig. 1.

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ADJUSTABLE VOLTAGE DRIVE

Filed Sept. 6, 1951 3 Sheets-Sheet 2

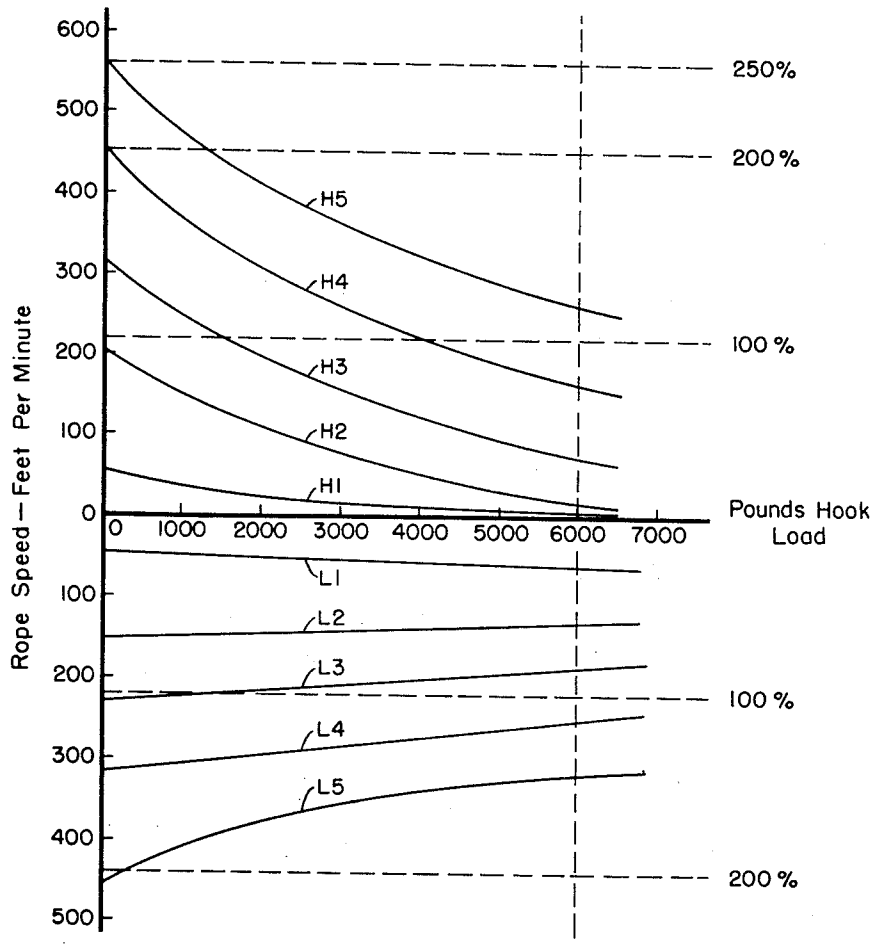

Fig. 2.

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ADJUSTABLE VOLTAGE DRIVE

Filed Sept. 6, 1951 3 Sheets-Sheet 3

Fig. 3.

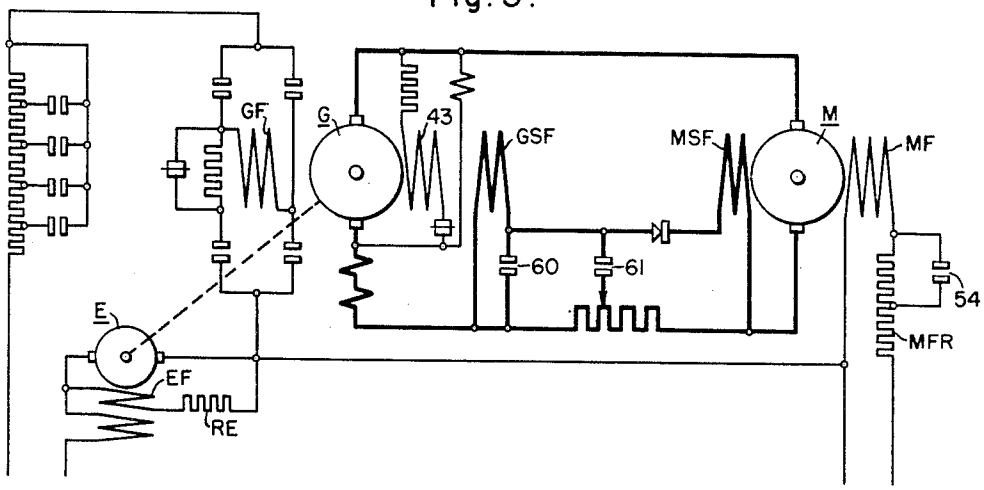
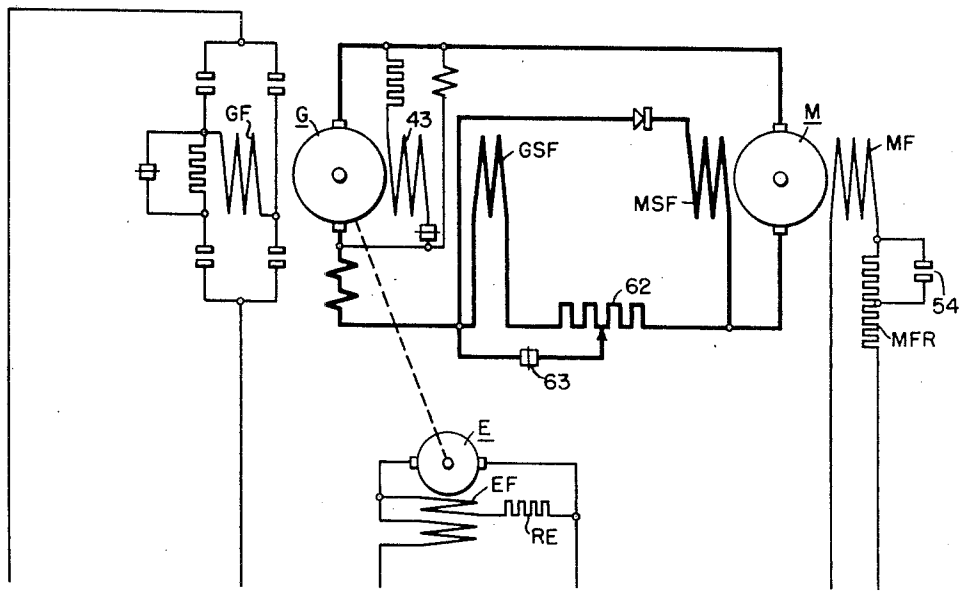


Fig. 4.



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United States Patent Office 2,785,362 Patented Mar. 12, 1957

2,785,362

ADJUSTABLE VOLTAGE DRIVE

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Application September 6, 1951, Serial No. 245,372

32 Claims. (Cl. 318—143)

Our invention relates to electric systems of control for driving an electric motor in either of two directions, and more specifically, our invention is directed to a variable voltage drive for a direct current motor coupled to drive a hoist, or similar load, and which systems provide highly desirable operating characteristics both for the hoisting of loads and for the lowering of loads.

One broad object of our invention is the provision of a drooping speed torque characteristic for both the driving operation of a motor and the overhauling operation of the motor.

A more specific object of our invention is the provision of a control, in a Ward-Leonard type of drive, for obtaining greater and greater decrease in speed of the motor with a rise in load on the motor with the selection of greater base speeds of operation of the motor.

Another somewhat specific object of our invention is the provision of a control, in a Ward-Leonard type drive, for obtaining, on a slow selected speed of the motor, a substantially constant speed regardless of the magnitude of the load from no-load to somewhat more than full-load.

Another somewhat specific object of our invention is the provision of a control, in a Ward-Leonard type of drive, for obtaining automatic operation of the generator as a differentially compound machine and the motor as a cumulatively compound machine when the voltage of the generator has one polarity and for obtaining non-compounding operation of the generator and motor when the voltage of the generator has opposite polarity, all without the use of elaborate switching means.

The objects hereinabove expressed are merely illustrative of the objects of our invention. Still other objects of our invention will become apparent from a study of the following specification and a study of the accompanying drawings, in which:

Figure 1 is a diagrammatic showing of a preferred embodiment of our invention as applied to hoist equipment;

Fig. 2 shows the speed-load characteristics we obtain with our system of control for both the hoisting operation of a load and lowering operation of an overhauling load; and

Figs. 3 and 4 are so-called straight-line diagrams of our invention illustrating two modifications thereof.

We show our invention as applied to a hoist but the invention is not limited to hoist applications, but will find utility on any motor reversing applications where the load characteristics have some similarity to the load characteristics of a hoist.

Referring more particularly to Fig. 1, the variable voltage control system includes a main generator G and an exciter E coupled to be driven by the constant speed induction motor IM disposed to be connected by means of the circuit breaker CB to the alternating current supply buses shown.

The main generator G has its armature connected in a loop circuit with the armature of the motor M. The generator G has a main field winding GF, a suicide winding 43 and a series field winding GSF. The motor M has a main field winding MF and a motor series field winding MSF. A rectifier 31 is connected in series with the motor series field winding to provide for a unidirectional energization of this field winding.

A master switch, or controller, MS is disposed to control the sequence of operation for both the hoisting operation of the hoist H mechanically coupled to the motor M, and the lowering of both non-overhauling and overhauling loads secured to the hoist cable.

The exciter E is provided with the exciter field EF and its adjustable rheostat RE and provides, when operated at normal speed, a constant potential source of direct current.

A better understanding of our invention may be had from a study of typical operations of the apparatus and the controller for all the positions both in the hoisting operation and the lowering operation of motor M.

Assuming that the circuit breaker CB is closed, to thus operate the induction motor IM to drive the exciter E and the generator G at constant speed, then the exciter E will have full voltage at its armature terminals. However, since the generator fields for generator G, and the fields for motor M are unexcited, it is apparent that the hoist will not be in operation. To effect an operation, the attendant must first close the emergency stop switch ES, whereupon a circuit is established from the positive armature terminal of the exciter through contact 1 of switch ES, conductor 2, controller segment 3, conductor 4, auxiliary switch 5 on the circuit breaker CB, contact 6 of the switch ES, actuating coil 7 of the low voltage relay LV, back contacts 8 of the overload relay OL, conductor 9 and contact 10 of the switch ES and the series field 11 of the exciter E to the negative terminal of the exciter.

The emergency stop switch is normally located in the housing of the master switch MS and is provided with a small lever, not shown, projecting from the master switch housing at the side thereof. Such disposition of the actuating lever makes quick operation of the switch ES possible when the need arises.

Operation of the low voltage relay LV causes the closing of contacts 12 which are in parallel with the controller segment 3, and thus thereafter make the operation of the low voltage relay independent of the position of the master switch or controller MS. The operation of low voltage relay LV also closes contacts 13 to thus connect the conductor 14 to the positive terminal of the exciter E.

If we assume that a hoisting operation is to be effected, and the attendant moves the controller to the first hoist position, then a circuit is established from the positive conductor 14 through the controller segment 15, conductor 16, actuating coil 17 of the brake relay BR to the negative conductor 9. Operation of the brake relay establishes a circuit from the positive conductor 2 through the resistor 18, the brake coil 19 and contacts 20 to the negative conductor 9. The brake B is thus released and the motor M thus assumes control of the load on the hoist H. In order that the motor may develop the proper torque, the operation of the switch ES connects the motor field MF, through the motor field rheostat MFR, across the positive and negative conductors 2 and 9 respectively. The motor field MF will thus be excited at a selected value for the hoisting operation.

Movement of the controller to the first hoist position also establishes a circuit through the actuating coil 21 of the kill-flux relay KF to thus open the circuit for the suicide field 43 at the contacts 22.

While the controller is still in the first hoist position, another circuit is established from positive conductor 14 through the controller segment 23, conductor 24, the

generator field GF, conductor 25, controller segment 26, and all of the sections of the generator field rheostat GFR to the negative conductor 9.

With the energization of the generator field G, an energizing circuit is established from the positive terminal of the generator G through the actuating coil 27 of the load relay LR, the actuating coil 28 of the overload relay OL, contacts 29 of the control relay 30, rectifier 31, the motor series field MSF, and the motor armature to the negative terminal of the generator G.

Since the motor field MF is fully energized and at the start the starting current is apt to be quite heavy, it is apparent that the motor series field MSF is heavily energized. The motor M thus develops a relatively large starting torque. However, since the generator field GF is energized with all the resistor sections of the generator field rheostat in its circuit, and the generator series field GSF is by-passed by contacts 29 of relay 30 on the first point hoisting, the voltage developed by the generator is relatively low and in consequence, the load is picked up very softly and the starting is effected with the minimum of shock on the mechanical system.

The speed load curve H1 represents the operating characteristic on the first point hoist, and it will be noted that the speed is quite low, particularly if the load is heavy, and that the speed is somewhat higher if the load is nearer the no-load value. From an operating standpoint, this is a very desirable feature since the shock on the mechanical system of a rapid start would be much greater if the load were heavy and the starting effected very rapidly.

It will be noted that the control relay 30 has a second back contact 32 for shunting a portion of the resistor 33 disposed in shunt relation to the motor series field MSF. By shunting few of the sections of resistor 33 the control of the motor series field may be modified to suit the requirements of the load characteristics that may be encountered in practice.

If the controller be moved to the second hoist position, the resistor section 38 in the generator field circuit is shunted by contact segment 37, to thus increase the generator field excitation. A circuit is also established from the positive conductor 14 through the controller segment 34, conductor 35, actuating coil 36 of the control relay 30 to the negative conductor 9. Operation of the control relay 30 opens the contacts 29 and 32 to thus increase the effect of the motor series field and modify the voltage characteristics of the generator G by the insertion of the generator series field GSF in the load circuit including the motor and generator. The winding arrangement of the generator series field is such that its effect is differential with respect to the main field GF to thus decrease the voltage of the generator with a rise in load. This provides a speed load characteristic as shown by H2. It will be noted that the acceleration of the load, if there is a heavy load, is still relatively low, but that the speed rise becomes greater and greater with a decrease in load on the hoist.

For the third, fourth and fifth positions of the controller MS in the hoist direction, all of the circuits remain as heretofore indicated except that the sections 39, 40 and 41 of the generator field rheostat GFR are successively shunted to thus increase the generator voltage in progressive steps. For each of the positions in the hoist direction, namely 3, 4 and 5, the speed load characteristic is represented by the curves H3, H4 and H5. From the second hoist position to the fifth hoist position for any load on the motor, it will be apparent that the speed rise is substantially directly proportional to the change in excitation of the generator, and that the rope speed may be varied from about 200 feet per minute in the second hoist position to 575 feet per minute on the fifth hoist position, which substantially represents a change in rope speed from 100% to 250%, with the rope speed about 120% at full load and 250% at no-load.

If the controller be rapidly moved from the fifth position to the off position, namely, the position shown, the energizing circuits for the brake relay BR, the control relay 30, and the generator main field GF are interrupted. However, since the motor will develop considerable counter E. M. F., the actuating coil 42 of the counter-electromotive force relay CV will be energized and in consequence, contacts 45 will be closed. This means that the kill-flux relay KF will remain energized since, as long as contacts 45 remain closed, the energization of the coil 21 is independent of the position of the controller. It is thus apparent that contacts 22 remain open for the time being. However, since the counter E. M. F. of the motor will drop rapidly, at some selected change in voltage coil 42 will be insufficiently energized to hold contacts 45 closed, and in consequence, coil 21 will become de-energized and close contacts 22, whereupon a dynamic braking circuit is established from the now positive output terminal of the motor M through a portion of resistor 33, contacts 32, coils 28 and 27, contacts 22, suicide field 43, resistor 44 to the negative motor terminal. Of course, the generator armature will also be connected in the dynamic braking circuit since this armature is in parallel to the circuit for the suicide field 43.

The timing arrangement of the brake relay BR is such that for most stopping operations, the dynamic braking circuit through the suicide field 43 is established for a sufficient period of time to bring the motor M substantially to rest before the contacts 20 open to set the brake B. This is of considerable advantage because substantially no slippage is encountered in the brake shoes, and thus long and reliable brake life is assured by our control arrangement.

If the motor M is to be operated in the lowering direction, the attendant moves the controller to the first lowering position, whereupon the controller segment 46 establishes a circuit for the brake relay and for the kill-flux relay KF exactly in the same manner that the controller segment 15 functions for the hoist operation. A circuit is also established from the positive conductor 14 through controller segment 50, conductor 25, generator field GF, and conductor 24, resistor 51, controller segment 52, and all of the resistor sections of the generator field rheostat GFR to the negative conductor.

Another circuit is established from the positive conductor 14 through the controller segment 47, magnetizing coil 48 of the time limit relay TL to the negative conductor 9. The time limit relay TL operates to open the contacts 49 to thus insert the extra resistor section 51 in the circuit of the generator field GF to provide a relatively low excitation for the generator G.

Another circuit is established from the positive conductor 2 through the motor field MF, conductor 53, controller segment 54, and conductor 55 to a selected point on the motor field rheostat MFR. The controller segment 54 thus shunts a considerable portion of the motor field rheostat to thus heavily excite the motor field MF and provide for a heavy starting torque and slow motor speed. Now, the heavy motor excitation coupled with the low voltage of the generator G provides a speed load characteristic as evidenced by the curve L1 of Fig. 2. It will be noted that the curve L1 provides for a substantially constant motor speed from no-load to full load for the first controller position.

Upon movement of the controller to the second lowering position, the excitation of the generator field is merely increased by shunting the section 38 of the generator field rheostat. In positions 3, 4 and 5 the other sections 39, 40 and 41 are successively shunted to thus increase the generator field excitation. For these successive positions, it will be noted that the speed torque curves represented by the curves L2, L3, L4 and L5

change somewhat in slope. The curve L2, except for providing a higher motor speed, still provides a substantially constant motor speed regardless of the variations in load.

On the fifth controller position, the controller segment 47 interrupts the circuit for the magnetizing coil 48 of the time limit relay TL. If the motor load is sufficiently low, the load relay LR drops out and in consequence, contacts 58 are opened. This means that the holding coil 57 of the time limit relay TL is deenergized and the result is that contacts 49 close on the fifth position of the controller to materially increase the generator excitation. This has a considerable advantage because if the load is not sufficiently low, contacts 58 remain closed, and contacts 49 remain open with the result that the generator field GF is not so heavily excited. The speed of the motor thus varies more and more with a change in load on the fifth position of the controller. The load relay LR is of the non-fluttering type and works in conjunction with the time limit relay TL so that it will measure the actual motor load without the accelerating load component and the circuit is so arranged that the generator voltage will stay below a certain value whenever the load to be lowered exceeds a certain percentage, thereby maintaining safe lowering speeds at all times. Further, the arrangement is such that the load relay does not become effective except on the last lowering position when the higher speeds might be encountered.

The stopping operation from the lowering operation will, of course, be substantially the same for the motor as when the controller is moved from the hoist position to the off position. In this case the closing of the suicide field circuit will again be delayed by the counterelectromotive force, and will effect dynamic braking on the motor M to bring it substantially to rest just a moment before the brake B sets.

In Fig. 3 we have shown a somewhat modified circuit for the generator differential series field and the motor series field, and by appropriate operation of the switches 60 and 61, the generator differential field may be utilized when the voltage of the generator is reversed, which is not the case when the embodiment shown in Fig. 1 is utilized. It will be noted that in the showing of Fig. 3, the rectifier is only in series with the motor field, and that a reverse excitation of the motor is not possible, and the transition from cumulative compound excitation of the motor for hoisting loads to non-compound excitation for lowering operation proceeds automatically in exactly the same manner as shown in Fig. 1.

In Fig. 4, we have shown a still further arrangement of the generator series field winding, and the motor series field winding, and by a suitable selection of the constants for the resistor 62 shown and appropriate operation of the switch 63 shunting the series field of the generator, the novel operating characteristics obtained with the showing in Fig. 1 may be obtained. However, it is also possible in this arrangement to utilize the generator series field during the lowering operation.

We do not wish to be limited to the embodiment and modifications shown, because we are aware that others, particularly after having had the benefit of the teachings of our invention, may devise similar circuits for accomplishing the same or substantially the same novel results with apparatus falling within the spirit of our invention.

We claim as our invention:

1. A variable voltage control system for a direct current motor which may be coupled to drive a hoist, or other load, comprising, in combination, a generator and motor each having an armature winding, said motor being connected to the generator to be operated thereby, a series field winding and a separately excited field winding for each of said dynamo-electric machines, an external source of energization for said separately excited field windings,

field reversing switch means for the separately excited field winding of the generator, a rectifier in series with the series field winding of the motor, the winding sense of the series field winding of the generator being differential with respect to its separately excited field winding and the winding sense of the series field of the motor and the polarity sense of the rectifier being such that the motor is a cumulative compound motor when the excitation direction of the separately excited field of the generator is such as to operate the motor in one selected direction.

2. A variable voltage control system for a direct current motor which may be coupled to drive a hoist, or similar other load, comprising, in combination, a generator and motor each having an armature winding, said motor being connected to the generator to be operated thereby, a series field winding and a separately excited field winding for each of said dynamo-electric machines, said generator also having a third field winding and a dynamic braking resistor connected in series with said third field winding, an external source of energization for said separately excited field windings, field reversing switch means for the separately excited field winding of the generator, a rectifier in series with the series field winding of the motor, the winding sense of the series field winding of the generator being differential with respect to its separately excited field winding and the winding sense of the series field of the motor and the polarity sense of the rectifier being such that the motor is a cumulative compound motor when the excitation direction of the separately excited field of the generator is such as to operate the motor in one selected direction, and control means operable upon opening of the field circuit of the separately excited field of the generator for connecting the third generator field winding, and the dynamic braking resistor in series therewith, to the armature terminals of the generator.

3. A variable voltage control system for a direct current motor which may be coupled to drive a hoist, or similar other load, comprising, in combination, a generator and motor each having an armature winding, said motor being connected to said generator to be operated thereby, a series field winding and a separately excited field winding for each of said dynamo-electric machines, said generator also having a third field winding and a dynamic braking resistor connected in series with said third field winding, an external source of energization for said separately excited field windings, field reversing switch means for the separately excited field winding of the generator, a rectifier in series with the series field winding of the motor, the winding sense of the series field winding of the generator being differential with respect to its separately excited field winding and the winding sense of the series field of the motor and the polarity sense of the rectifier being such that the motor is a cumulative compound motor when the excitation direction of the separately excited field of the generator is such as to operate the motor in one selected direction, control means operable upon opening of the field circuit of the separately excited field winding of the generator for connecting the third generator field winding, and the dynamic braking resistor in series therewith, to the armature terminals of the generator, and means responsive to a selected decrease in generator voltage for altering the operation of said control means.

4. A variable voltage control system for a direct current motor comprising, in combination, a generator and motor each having an armature winding, a series field winding, and a separately excited main field winding, a source of direct current potential for exciting the main field windings, control switch means operable in one direction for separately exciting the main motor field winding at a given value and the generator main field winding in a given sense to effect operation of the motor in one direction, a rectifier, said motor and generator armature

windings, the motor and generator series field windings and said rectifier being connected in a loop circuit, during operation of said motor in said one direction, the winding sense of the generator series field winding being differential to the generator main field winding and the rectifying sense and the winding sense of the motor main field winding being such that the motor is a cumulative compound motor.

5. A variable voltage control system for a direct current motor comprising, in combination, a generator and motor each having an armature winding, a series field winding, and a separately excited main field winding, a third field winding for the generator, a source of direct current potential for exciting the main field windings, control switch means operable in one direction for separately exciting the main motor field winding at a given value and the generator main field winding in a given sense to effect operation of the motor in one direction, a rectifier, said motor and generator armature windings, the motor and generator series field windings and said rectifier being connected in a loop circuit, during operation of said motor in said one direction, the winding sense of the generator series field winding being differential to the generator main field winding and the rectifying sense and the winding sense of the motor main field winding being such that the motor is a cumulative compound motor, and means for connecting the said third field winding to the motor armature terminals to effect dynamic braking of the motor and to kill the generator excitation.

6. A variable voltage control system for a direct current motor comprising, in combination, a generator and motor each having an armature winding, a series field winding, and a separately excited main field winding, a source of direct current potential for exciting the main field windings, control switch means operable in one direction for separately exciting the main motor field winding at a given value and the generator main field winding in a given sense to effect operation of the motor in one direction and operable in an opposite direction for separately exciting the motor main field winding at a value higher than said given value and the generator main field winding in an opposite sense to effect reverse operation, a rectifier, said motor and generator armature windings, the motor and generator series field windings and said rectifier being connected in a loop circuit, during operation of the motor in said one direction the winding sense of the generator series field winding being differential to the generator main field winding and the rectifying sense and the winding sense of the motor main field winding being such that the motor is a cumulative compound motor, and operable during reverse operation for disconnecting the series field windings from the loop circuit.

7. A variable voltage control system for a direct current motor comprising, in combination, a generator and motor each having an armature winding, a series field winding, and a separately excited main field winding, a source of direct current potential for exciting the main field windings, control switch means operable in one direction for separately exciting the main motor field winding at a given value and the generator main field winding in a given sense to effect forward operation, a rectifier, said motor and generator armature windings, the motor and generator series field windings, and said rectifier being connected in a loop circuit, during forward operation the winding sense of the generator series field winding being differential to the generator main field winding and the rectifying sense and the winding sense of the motor main field winding being such that the motor is a cumulative compound motor, a shunting circuit for the series field windings of the generator and motor, and means for changing the impedance of the shunting circuit during forward operation.

8. A variable voltage control system for a direct current motor comprising, in combination, a generator and motor each having an armature winding, a series field winding, and a separately excited main field winding, a third field winding for the generator, a source of direct current potential for exciting the main field windings, control switch means operable in one direction for separately exciting the main motor field winding at a given value and the generator main field winding in a given sense to effect forward operation and operable in an opposite direction for separately exciting the motor main field winding at a value higher than said given value and the generator main field winding in an opposite sense to effect reverse operation, a rectifier, said motor and generator armature windings, the motor and generator series field windings and said rectifier being connected in a loop circuit, during forward operation the winding sense of the generator series field winding being differential to the generator main field winding and the rectifying sense and the winding sense of the motor main field winding being such that the motor is a cumulative compound motor, and operable during reverse operation for disconnecting the series field windings from the loop circuit, and means for connecting the said third field winding to the motor armature terminals to effect dynamic braking of the motor and to kill the generator excitation.

9. A variable voltage control system for a direct current motor comprising, in combination, a generator and motor each having an armature winding, a series field winding, and a separately excited main field winding, a third field winding for the generator, a source of direct current potential for exciting the main field windings, control switch means operable in one direction for separately exciting the main motor field winding at a given value and the generator main field winding in a given sense to effect forward operation, a rectifier, said motor and generator armature windings, the motor and generator series field windings and said rectifier being connected in a loop circuit, during forward operation the winding sense of the generator series field winding being differential to the generator main field winding and the rectifying sense and the winding sense of the motor main field winding being such that the motor is a cumulative compound motor, a shunting circuit for the series field windings of the generator and motor, and means for changing the impedance of the shunting circuit during forward operation, and means for connecting the said third field winding to the motor armature terminals to effect dynamic braking of the motor and to kill the generator excitation.

10. A variable voltage control system for a direct current motor comprising, in combination, a generator and motor each having an armature winding, a series field winding, and a separately excited main field winding, a third field winding for the generator, a source of direct current potential for exciting the main field windings, control switch means operable in one direction for separately exciting the main motor field winding at a given value and the generator main field winding in a given sense to effect forward operation and operable in an opposite direction for separately exciting the motor main field winding at a value higher than said given value and the generator main field winding in an opposite sense to effect reverse operation, a rectifier, said motor and generator armature windings, the motor and generator series field windings and said rectifier being connected in a loop circuit, during hoisting operation, the winding sense of the generator series field winding being differential to the generator main field winding and the rectifying sense and the winding sense of the motor main field winding being such that the motor is a cumulative compound motor, a shunting circuit for the series field windings of the generator and motor, and means for changing the impedance of the shunting circuit during forward operation, and operable during reverse operation for disconnecting the series field windings from the

loop circuit, and means for connecting the said third field winding to the motor armature terminals to effect dynamic braking of the motor and to kill the generator excitation.

11. A variable voltage control system for a direct current motor which may be coupled to drive a hoist, or similar other load, comprising, in combination, a generator and motor each having an armature winding, said motor being connected to the generator to be driven thereby, a series field winding and a separately excited field winding for each of said dynamo-electric machines, said generator also having a third field winding and a dynamic braking resistor connected in series with said third field winding, an external source of energization for said separately excited field winding, field reversing switch means for the separately excited field of the generator, a rectifier in series with the series field winding of the motor, the winding sense of the series field winding of the generator being differential with respect to its separately excited field winding and the winding sense of the series field of the motor and the polarity sense of the rectifier being such that the motor is a cumulative compound motor when the excitation direction of the separately excited field of the generator is such as to operate the motor in the hoist direction, control means, operable upon opening of the excitation circuit of the separately excited generator field winding, for connecting the third generator field winding, and the dynamic braking resistor in series therewith, to the armature terminals of the generator to thus provide a dynamic braking circuit for the motor and an excitation for the generator to kill the residual flux of the generator.

12. A variable voltage control system for a direct current motor which may be coupled to drive a hoist, or similar other load, comprising, in combination, a generator and motor each having an armature winding, said motor being connected to the generator to be driven thereby, a series field winding and a separately excited field winding for each of said dynamo-electric machines, said generator also having a third field winding and a dynamic braking resistor connected in series with said third field winding, an external source of energization for said separately excited field windings, field reversing switch means for the separately excited field of the generator, a rectifier in series with the series field winding of the motor, the winding sense of the series field winding of the generator being differential with respect to its separately excited field winding and the winding sense of the series field winding of the motor and the polarity sense of the rectifier being such that the motor is a cumulative compound motor when the excitation direction of the separately excited field of the generator is such as to operate the motor in the hoist direction, control means, operable upon opening of the circuit for the separately excited generator field winding, for connecting the third generator field winding and the resistor in series therewith, to the generator armature terminals to thus provide a dynamic braking circuit, including the generator armature connected in parallel with the third field winding and dynamic braking resistor in series therewith, and means responsive to the counter-electromotive force of the motor for modifying the circuit arrangement of the dynamic braking circuit.

13. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, a main field winding for the generator, a main field winding for the motor, said loop circuit including the armature windings of the generator and motor, a generator series field winding, a shunting circuit including switching means for shunting the generator series field winding, a rectifier, a motor series field winding, and an adjustable impedance connectible in shunt relation to the generator series field winding, the rectifier, and the motor series field winding, and rheostatic control means for changing the magnitude of the exciting current of the generator field winding from zero over selected positive and negative ranges.

14. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, a main field winding for the generator, a main field winding for the motor, a motor load-current responsive relay having an actuating coil, said loop circuit including the armature windings of the generator and motor, the actuating coil of said load-current responsive relay, a generator series field winding, a shunting circuit including switching means for shunting the generator series field winding, a rectifier, a motor series field winding, and an adjustable impedance connectible in shunt relation to the generator series field winding, the rectifier, and the motor series field winding, and rheostatic control means for changing the magnitude of the exciting current of the generator field winding from zero over selected positive and negative ranges, means responsive to the operation of the load-current responsive relay for increasing the excitation of the generator main field winding beyond the ranges of the rheostatic control means.

15. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, a main field winding for the generator, a main field winding for the motor, said loop circuit including the armature windings of the generator and motor, a generator series field winding, a shunting circuit including switching means for shunting the generator series field winding, a rectifier, a motor series field winding, and an adjustable impedance connectible in shunt relation to the generator series field winding, the rectifier, and the motor series field winding, rheostatic control means for changing the magnitude of the exciting current of the generator field winding from zero over selected positive and negative ranges, a third field winding for the generator, and means responsive to a selected drop in the counter-electromotive force of the motor, upon deenergization of the main field winding of the generator for connecting the third generator field winding across the generator armature terminals to thus provide a dynamic braking circuit for the motor including the generator armature winding and the third field winding and the adjustable impedance.

16. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, a main field winding for the generator, a main field winding for the motor, a motor load-current responsive relay having an actuating coil, said loop circuit including the armature windings of the generator and motor, the actuating coil of said load-current responsive relay, a generator series field winding, a shunting circuit including switching means for shunting the generator series field winding, a rectifier, a motor series field winding, and an adjustable impedance connectible in shunt relation to the generator series field winding, the rectifier, and the motor series field winding, rheostatic control means for changing the magnitude of the exciting current of the generator field winding from zero over selected positive and negative ranges, means responsive to the operation of the load-current responsive relay for increasing the excitation of the generator main field winding beyond the ranges of the rheostatic control means, a third field winding for the generator, and means responsive to a selected drop in the counter-electromotive force of the motor upon deenergization of the main field winding of the generator for connecting the third generator field winding across the generator armature terminals to thus provide a dynamic braking circuit for the motor including the generator armature winding and the third field winding and the adjustable impedance.

17. In a Ward-Leonard drive, a system of control comprising in combination, a generator and motor having their armature windings connected in a loop circuit, a main field winding for the generator, a main field wind-

ing for the motor, a motor load responsive relay having an actuating coil, said loop circuit including the actuating coil of said load responsive relay, a generator series field winding having a winding sense that is differential to the generator main field winding, a shunting circuit for the generator series field windings including switching means for closing and opening the shunting circuit, a rectifier, a motor series field winding connected in series with the rectifier, and an adjustable resistor disposed to be connected in shunt relation to the generator series field winding, the rectifier, and the motor series field winding, the polarity sense of the rectifier being such that the motor series field winding acts cumulatively to the main motor field winding when the output voltage of the generator has a given polarity, rheostatic control means for changing the excitation of the main field winding of the generator to vary the motor speed, means responsive to the operation of the load responsive relay for increasing the excitation of the main generator field winding beyond the range of the rheostatic means, a third field winding for the generator, and means responsive to a selected drop in the counter-electromotive force of the motor, upon deenergization of the main field winding of the generator, for connecting the third generator field across the generator armature terminals to thus provide a dynamic braking circuit for the motor, said dynamic braking circuit including the motor armature winding, the adjustable resistor, the generator armature winding and said third generator field winding.

18. In a Ward-Leonard drive, a system of control comprising in combination, a generator and motor having their armature windings connected in a loop circuit, a main field winding for the generator, a main field winding for the motor, a motor load responsive relay having an actuating coil, said loop circuit including the actuating coil of said load responsive relay, a generator series field winding having a winding sense that is differential to the generator main field winding, a shunting circuit for the generator series field windings including switching means for closing and opening the shunting circuit, a rectifier, a motor series field winding connected in series with the rectifier, and an adjustable resistor disposed to be connected in shunt relation to the generator series field winding, the rectifier, and the motor series field winding, the polarity sense of the rectifier being such that the motor series field winding acts cumulatively to the main motor field winding when the output voltage of the generator has a given polarity, rheostatic control means for changing the excitation of the main field winding of the generator to vary the motor speed, means responsive to the operation of the load responsive relay for increasing the excitation of the main generator field winding beyond the range of the rheostatic means, a third field winding for the generator, and means responsive to a selected drop in the counter-electromotive force of the motor, upon deenergization of the main field winding of the generator, for connecting the third generator field winding across the generator armature terminals to thus provide a dynamic braking circuit for the motor, said dynamic braking circuit including the motor armature winding, the adjustable resistor, the generator armature winding and said third generator field winding.

19. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, main field windings for the generator and motor, said loop circuit further including a series field winding for the generator, a shunting circuit including switching means for effecting the shunting of the generator series field winding, a motor series field winding, a rectifier connected in series with the motor series field winding, and rheostatic control means operatively associated with the shunting circuit for the generator series field winding and connected in relation to the motor series field winding for changing the excitation current of the motor series field winding, and rheostatic control means for the generator main field winding for controlling the motor speed.

20. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings conected in a loop circuit, main field windings for the generator and motor, said loop circuit further including a generator series field winding, a rectifier and a motor series field winding all three connected in a series circuit, a resistor connected in parallel to said series circuit, and generator series field shunting circuit means connected at any selected point on said resistor and including switching means for effecting the shunting of the generator series field winding, and rheostatic control means for the main field winding of the generator for controlling the speed of the motor.

21. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, main field windings for the generator and motor, said loop circuit further including a series field winding for the generator, a shunting circuit including switching means for effecting the shunting of the generator series field winding, a motor series field winding, a rectifier connected in series with the motor series field winding, and rheostatic control means operatively associated with the shunting circuit for the generator series field winding and connected in relation to the motor series field winding for changing the excitation current of the motor series field winding, rheostatic control means for the main field winding of the generator for changing the generator excitation from zero by successive values to a selected high value, rheostatic control means for changing the excitation of the main field winding of the motor, and means operable by said rheostatic control means for causing the operation of said switching means included in the loop circuit to effect the shunting operations with respect to the generator series field winding and the said resistor at a time when the main generator field winding is excited at a minimum above zero excitation.

22. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, main field windings for the generator, rheostatic means for varying the excitation of the generator main field winding from zero in successive steps to a selected high value, rheostatic control means for the main field winding of the motor, said loop circuit further including a series field winding, a rectifier, and a series field winding for the motor all three connected in a series circuit, a resistor having a plurality of sections connected in parallel to said series circuit, a shunt circuit for the generator series field winding, a shunt circuit for said resistor connectible across any selected number of resistor sections, switching means for closing the shunt circuits, and means responsive to the operation of said rheostatic means of the main field winding of the generator for effecting the closing of said switching means at zero excitation of the main field winding of the generator and for the lowest excitation of the main field winding of the generator above the zero excitation and for effecting the opening of said switching means for all values of excitation of the main field winding of the generator above said mentioned lowest excitation.

23. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, main field windings for the generator, rheostatic means for varying the excitation of the generator main field winding from zero in successive steps to a selected high value, means responsive to the motor load current for effecting an excitation of the main field winding of the generator greater than said selected high value when the motor load current is below a selected value, rheostatic control means for the main field winding of the motor, said loop circuit further including a series field winding, a rec-

tifier, and a series field winding for the motor all three connected in a series circuit, a resistor having a plurality of sections connected in parallel to said series circuit, a shunt circuit for the generator series field winding, a shunt circuit for said resistor connectible across any selected number of resistor sections, switching means for closing the shunt circuits, and means responsive to the operation of said rheostatic means of the main field winding of the generator for effecting the closing of said switching means at zero excitation of the main field winding of the generator and for the lowest excitation of the main field winding of the generator above the zero excitation and for effecting the opening of said switching means for all values of excitation of the main field winding of the generator above said mentioned lowest excitation.

24. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, main field windings for the generator, rheostatic means for varying the excitation of the generator main field winding from zero in successive steps to a selected high value, rheostatic control means for the main field winding of the motor, said loop circuit further including a series field winding, a rectifier, and a series field winding for the motor all three connected in a series circuit, a resistor having a plurality of sections connected in parallel to said series circuit, a shunt circuit for the generator series field winding, a shunt circuit for said resistor connectible across any selected number of resistor sections, switching means for closing the shunt circuits, and means responsive to the operation of said rheostatic means of the main field winding of the generator for effecting the closing of said switching means at zero excitation of the main field winding of the generator and for the lowest excitation of the main field winding of the generator above the zero excitation and for effecting the opening of said switching means for all values of excitation of the main field winding of the generator above said mentioned lowest excitation, a third field winding for the generator, control switching means for connecting the third field winding across the generator armature winding terminals, the winding sense of said third field winding being differential to the main field winding of the generator, and means responsive to a selected decrease of the voltage across the generator armature winding terminals for effecting the closing of said control switching means.

25. In a system of control for a Ward-Leonard drive, in combination, a generator and motor having their armature windings connected in a loop circuit, main field windings for the generator, rheostatic means for varying the excitation of the generator main field winding from zero in successive steps to a selected high value, means responsive to the motor load current for effecting an excitation of the main field winding of the generator greater than said selected high value when the motor load current is below a selected value, rheostatic control means for the main field winding of the motor, said loop circuit further including a series field winding, a rectifier, and a series field winding for the motor all three connected in a series circuit, a resistor having a plurality of sections connected in parallel to said series circuit, a shunt circuit for the generator series field winding, a shunt circuit for said resistor connectible across any selected number of resistor sections, switching means for closing the shunt circuits, and means responsive to the operation of said rheostatic means of the main field winding of the generator for effecting the closing of said switching means at zero excitation of the main field winding of the generator and for the lowest excitation of the main field winding of the generator above the zero excitation and for effecting the opening of said switching means for all values of excitation of the main field winding of the generator above said mentioned lowest excitation, a third field winding for the generator, control switching means for connecting the third field winding across the generator armature winding terminals, the winding sense of said third field winding being differential to the main field winding of the generator, and means responsive to a selected decrease of the voltage across the generator armature winding terminals for effecting the closing of said control switching means.

26. In a variable voltage system for hoists, a generator, a compound motor supplied thereby and having a series field winding, means to effect reverse operations of said motor by reversing the polarity of a field winding of said generator and to vary the excitation of said generator to provide for said motor a plurality of hoist and lowering speed points, and means associated with the former means including a rectifier to effect inclusion of said motor series field winding on all lowering points under overhauling load conditions and to exclude said motor series field winding from circuit under power lowering conditions.

27. In a variable voltage system for hoists, in combination, a generator, a compound motor supplied thereby and having an auxiliary series field winding, means to effect reverse operations of said motor by reversing the polarity of field winding of said generator and to vary the excitation of said generator to provide for said motor a plurality of hoist and lowering speed points, and rectifier means connected in series with said motor auxiliary field winding for effecting inclusion of said latter winding on all lowering points under overhauling conditions.

28. In a variable voltage system for hoists, in combination, a generator, a compound motor supplied thereby and having an auxiliary series field winding, control means for said generator for effecting reverse operation of said motor and providing a plurality of speed points therefor, and rectifier means connected in series with said auxiliary series field winding for permitting energization thereof under certain conditions of hoist operation and blocking energization thereof under certain other conditions.

29. In a variable voltage system for hoists, in combination, a generator, a compound motor connected in a loop circuit therewith and having an auxiliary field winding connected in parallel with a voltage drop resistor in said loop circuit, control means for said generator for varying the loop circuit voltage and for reversing the polarity thereof, and a blocking rectifier connected in series with said motor auxiliary winding to prevent energization thereof during light line lowering conditions.

30. In a variable voltage system for hoists, in combination, a generator, a compound motor connected in a loop circuit therewith and having an auxiliary field winding, a voltage drop resistor in said loop circuit with said auxiliary field winding connected in parallel therewith, control means for said generator to effect reversal of the voltage polarity in said loop circuit and consequent reversal of said motor and for varying the excitation of said generator to provide for said motor a plurality of hoist and lowering speed points, and a blocking rectifier, said rectifier being connected in series with said auxiliary field winding to prevent energization thereof when said motor is driven in the lowering direction by said generator.

31. In a variable voltage control system for hoists, in combination, a generator, a compound motor supplied thereby and having an auxiliary series field winding to be excluded from circuit under certain conditions, means to effect reverse operations of said motor by reversing the polarity of a field winding of said generator and to vary the excitation of said generator to provide for said motor a plurality of hoist and lowering speed points, and means responsive to direction of load current through the armature of said motor to disconnect said auxiliary series field winding from circuit for power lowering, said last mentioned means comprising a rectifier connected in series with said auxiliary field winding.

32. In a variable voltage control system for hoists,

in combination, a direct current motor, said motor having an auxiliary field winding, a voltage drop resistor connected in parallel with said winding and in series with the power circuit of said motor, and a blocking rectifier connected in series with said auxiliary winding whereby the energization of said winding is made dependent upon the direction of current flow through said motor.

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