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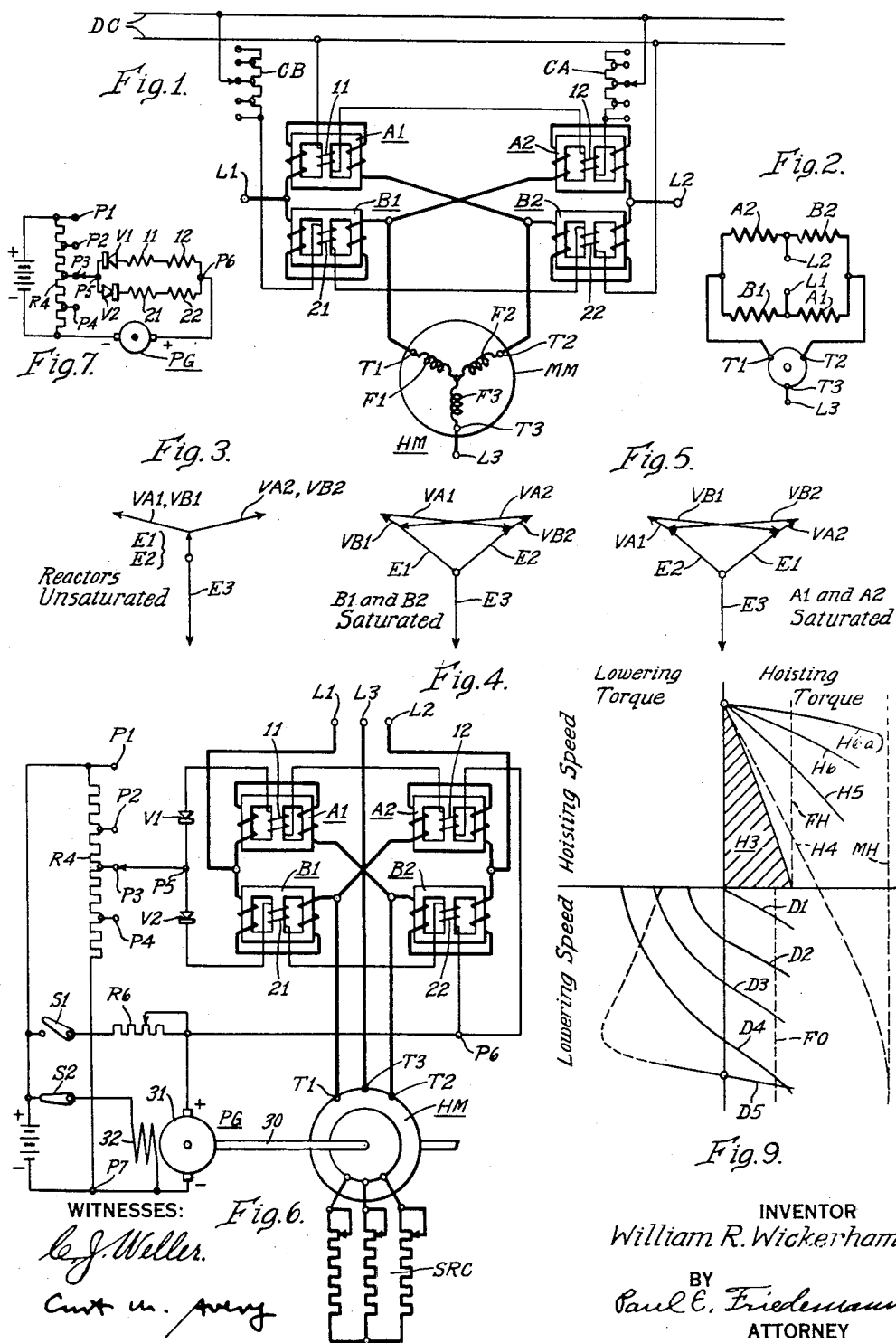
W. R. WICKERHAM

2,440,319

ALTERNATING CURRENT HOIST CONTROL

Filed Feb. 29, 1944

2 Sheets-Sheet 1



WITNESSES:
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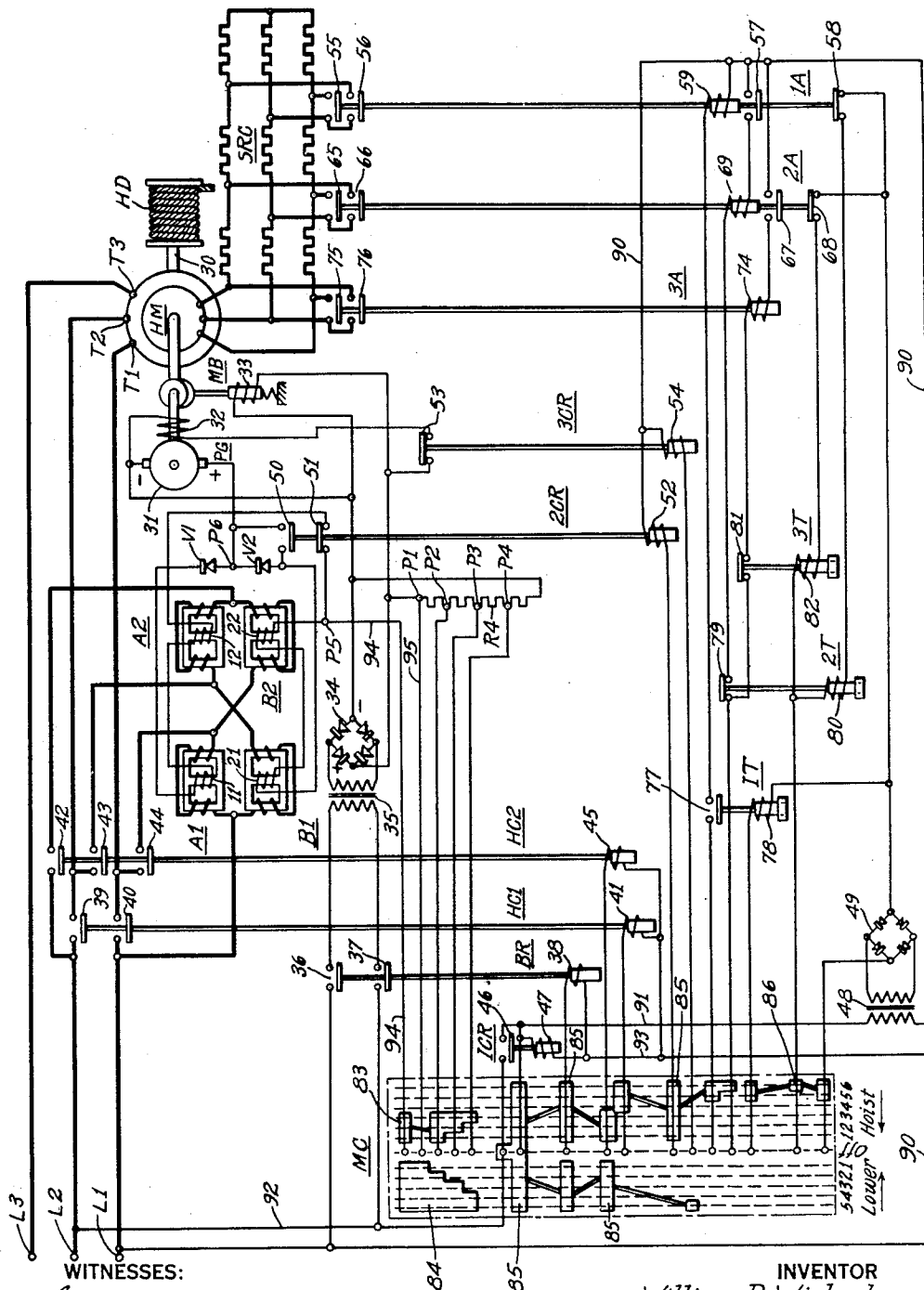
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2 Sheets-Sheet 2



WITNESSES:

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Fig. 8.

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ALTERNATING CURRENT HOIST CONTROL

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Application February 29, 1944, Serial No. 524,387

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My invention relates to control systems for alternating current motors on cranes, mine hoists, and other hoisting or elevating devices, and has the general object of improving the torque conditions of the hoist motor for deceleration or for lowering overhauling loads at reduced speeds. In this respect, and as regards other features, the invention is related to those of my copending applications Serial No. 513,351, now Patent Number 2,386,580 of October 9, 1945, and Serial No. 513,352, now Patent No. 2,386,581 of October 9, 1945, both filed December 8, 1943.

Three methods of controlling the speed of alternating current hoist motors during lowering or retardation are in use at the present time:

1. Alternating-current-excited dynamic loading,
2. Direct-current-excited dynamic braking, and
3. Countertorque operation.

Each of these methods has characteristic advantages and shortcomings over the two others, none of them being satisfactory in all essential respects. Alternating-current excited dynamic braking requires relatively simple operating means but provides a rather limited torque, for instance of about 100% at 100% rated speed, and draws an excessive input current of about 200% to 300% normal in two of the three lines of a three-phase supply system. Direct-current excited braking requires an additional direct-current exciter but affords a better speed control, the current input being about 150% normal, while the torque is limited to about 150% normal. The so-called "counter torque" method is superior in permitting an unlimited torque up to pull out, but entails the disadvantage of an unstable speed control due to the fact that there is little change in torque with change in speed, and has also the drawback that the motor will reverse its rotation when zero speed is reached unless special means are used for removing the motor from the line in that moment.

It is a more specific object of my invention to provide a hoist motor control which affords the desirable high torque characteristic of the countertorque method when lowering at high speed without incurring the instability of speed control and the tendency to reverse of this method.

In another aspect, my invention aims at providing a hoist control system which offers the advantage of a greatly reduced or reversed torque at lowest lowering speeds similar or superior to the alternating-current and direct-current excited braking methods, while permitting a much

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higher torque when lowering at higher operating speeds.

Another object, allied to the foregoing, is to combine in a hoist control the favorable low-speed torque characteristics of the above-mentioned braking methods with the preferable high-speed torque characteristics of countertorque operation during lowering operations of the hoist while maintaining the current input in moderate limits comparable to those of alternating current excited braking performance.

An essential object of my invention is also to attain low torques at subsynchronous speed. According to known methods, a subsynchronous speed can be obtained by changing during the control operation the internal field connections of the motor, but this requires a special motor design. In contrast thereto, the present invention aims at achieving a similar or superior result with standard type induction motors, such as wound rotor motors, with star or delta connected field windings whose interconnection is not changed or severed at any step of the control operation.

In order to achieve these objects, and in accordance with an essential feature of my invention, a hoist control system is equipped with multiphase circuit means for energizing the hoist motor to operate for hoisting and lowering, and contains voltage controlling circuit means which are so arranged that they permit an asymmetrical change of the component phase voltages thereby producing a controllable unbalance of the resultant multiphase primary motor voltage in certain selective steps of the control operation, especially when energizing the motor for lowering at low speed. These controllable circuit means are disposed between the primary motor terminals and the current source so that all appertaining control devices are extraneous of the motor and do not affect the internal connections of the field windings or other components of the motor proper.

According to another feature of my invention, the voltage unbalancing circuit means just referred to consists of controllable impedance devices so arranged in the energizing motor connections that the variations of their impedance affects the phase voltages differently by producing correspondingly different voltage drops across the respective impedance devices thereby also altering the voltage drop across the respective terminals of the motor.

According to a further feature of my invention, subsidiary to the foregoing, the controllable cir-

cuit means or impedance devices are designed and connected for varying two phase voltages of a three-phase hoist motor while the third phase voltage remains at its normal value.

In another aspect of the invention, the above-mentioned circuit means or impedance devices are controlled by an operator-actuated master controller with a number of selective control positions which serves also for controlling the direction of rotation and the secondary resistance circuit of the motor. As a result, the voltage unbalancing means become effective automatically at the proper setting of the master controller, especially when lowering.

In another aspect of my invention the above-mentioned voltage unbalancing circuit means are automatically controlled in dependence upon the motor speed.

One of the more specific features of my invention is to design the voltage unbalancing circuit means with such a range of controllable adjustment that the obtainable unbalance causes a reversal of the torque. According to another more specific feature, the voltage controlling means are of the potentiometric type, that is, they consist of variable impedances or resistances. A preferred way of applying these potentiometric means is to interpose between the motor and the terminals of the supply circuit a balanceable network of inductance coils.

According to another feature of my invention, the above-mentioned variable circuit means consist of saturable reactors whose reactance windings are inserted in all but one phase of the line and whose control or premagnetizing windings are energized in dependence on the controller adjustment so as to increase the effective reactance with decreasing lowering speeds.

These and other objects and features of my invention will be apparent from the following description of the embodiments illustrated in the drawings, in which:

Figure 1 shows the diagram of a motor control system operating with an unbalanced primary voltage in accordance with the invention.

Fig. 2 is a schematic diagram representing a simplified showing of a potentiometric or autotransformer circuit underlying the system according to Fig. 1.

Figs. 3, 4 and 5 are vector diagrams representing the voltage conditions occurring in a system according to Figs. 1 and 2 at three different control adjustments of the voltage biasing devices.

Fig. 6 is the basic circuit diagram of another embodiment in which the control of the primary motor voltage is dependent upon the speed of the motor and hence automatically varied when the motor speed changes.

Fig. 7 is a simplified schematic showing of the control circuit employed in the system according to Fig. 6.

Fig. 8 represents a complete hoist control system including all essential auxiliary apparatus, and

Fig. 9 is a diagram of the different speed torque characteristics corresponding to different positions of the master controller in a system according to Fig. 8.

Referring to the motor control system according to Fig. 1, a three-phase induction motor HM has its field terminals T1, T2 and T3 connected with the three terminals L1, L2 and L3, respectively, of an alternating current supply line. The motor is illustrated as having three star-connected field windings F1, F2 and F3 although it

will be understood from the following that the internal field connections are not essential to the present invention since they are not changed during the control operation and since this operation depends on the polarity and ratio or distribution of the three-phase voltages across the motor terminals T1, T2 and T3, regardless of whether a star or delta connection of the field windings is employed. The line terminal L3 is directly connected with the motor terminal T3. Between the motor terminals T1 and T2 and the line terminals L1 and L2 a network of variable inductance devices is provided. These devices consist of saturable reactors and are denoted by A1, A2 and B1 and B2. The main inductance coils of reactors A1 and B2 are connected across the terminals L1 and L2 in parallel to the inductance windings of reactors B1 and A2. The magnet core of each reactor carries a premagnetizing winding 11, 12, 21 or 22. The premagnetizing control windings 11 and 12 of the reactors A1 and A2, respectively, are series-connected to a direct-current source DC, a control resistor CA being interposed in order to vary the premagnetizing current from a low or zero value up to a magnitude at which the magnet cores A1 and A2 are saturated. When the control current adjusted by CA is zero or at a minimum, the reactors A1 and A2 are not premagnetized and hence unsaturated so that the inductive resistance of these reactors is at a maximum. When the resistor CA is adjusted for saturation, the inductive resistance of these reactors is at a minimum. The control coils 21 and 22 of the reactors B1 and B2, respectively, are series-connected with the current source DC through a control resistor CB, and operate in the same manner as the reactors A1 and A2. The four reactors are similar as to their magnetic and electric dimensions.

The operation of the system will be readily understood from the schematic diagram of Fig. 2 showing the reactors A1, A2, B1 and B2 as variable resistors. It will be seen from Fig. 2 that the connection of the resistors with the line terminals L1, L2 and the motor terminals T1, T2 represents a potentiometric or autotransformer circuit of the Wheatstone bridge type. If the inductance magnitudes of all four devices A1, A2, B1 and B2 are equal, for instance if in the system according to Fig. 1 the control coils 11, 12, 21 and 22 are disconnected and hence the reactors unsaturated, the bridge circuit is balanced so that the potentials appearing in any selected moment on terminals T1 and T2 are equal. In this case there is no voltage drop between the motor terminals T1 and T2 so that the motor is energized for single-phase operation with the result that its torque is zero. When the inductive resistances of devices A1 and A2 are decreased in the same direction and by the same amount, the bridge circuit becomes unbalanced so that the potential at terminal T1 approaches that of line terminal L2 while the potential of motor terminal T2 approaches that of terminal L1. Similarly, when the inductance of B1 and B2 is decreased as compared with that of A1 and A2, the bridge assumes an unbalance in the opposite direction so that potential at motor terminal T1 approaches that of line terminal L1 while the potential of T2 approaches that of line terminal L2. In both cases of unbalance the motor is energized by a three-phase voltage and produces three-phase torque, this torque being in one case opposite to that occurring in the other.

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The just-mentioned operation of the potentiometric or autotransformer type network is further elucidated by the vector diagrams shown in Figs. 3, 4 and 5. In Fig. 3 the vectors denoted by E1, E2 and E3 represent the phase voltages across the field coils F1, F2 and F3, respectively, of the motor HM shown in Fig. 1. The vectors VA1 and VA2 are indicative of the voltage across the respective reactors A1 and A2 which are of the same magnitude and direction as the voltages VB1 and VB2 across the reactors B1 and B2 respectively. The diagram of Fig. 3 represents a control condition in which all four reactors are unsaturated so that the reactors have maximum inductance. When reactors B1 and B2 are premagnetized up to saturation by adjusting the control resistor CB in Fig. 1 accordingly, the voltage conditions of the system are similar to those underlying the vector scheme in Fig. 4, the reference characters in this figure having the same meaning as in Fig. 3. It will be seen from the diagram that with both reactors B1 and B2 saturated, reactors A1 remaining unsaturated, the motor is energized by a three-phase voltage and produces a torque whose direction is in accordance with the sequence E1, E2, E3. When reactors A1 and A2 are saturated by adjusting their control resistance CA accordingly, while reactors B1 and B2 remain unsaturated, the voltage conditions assume the relation indicated in the diagram of Fig. 5. According to this diagram the sequence of the phase voltages E1, E2 and E3 is reversed, so that the motor is energized by a three-phase voltage for a torque opposite to that obtained under the conditions represented by Fig. 4.

The foregoing explanation shows that a control system according to the invention permits varying the speed torque characteristic of a multiphase motor without necessitating the use of contactors in the primary energizing circuit even in cases where a reversal of the torque is required.

As will be shown in the following, the adjustment of the control devices CB and CA can be effected by manual means, for instance, by the master controller customarily employed in hoist control systems. However, it is also possible, according to the invention, to provide an automatic control of the voltage biasing devices or to combine a manual control with such an automatic control. An embodiment exemplifying these possibilities is represented by Fig. 6.

The motor control system according to Fig. 6 is provided with a wound rotor motor HM with a controllable secondary resistance circuit SRC. The motor terminals T1, T2 and T3 are connected with the line terminals L1, L2 and L3 in the same manner as shown in Fig. 1 so that the voltage regulating reactors A1, A2, B1 and B2 are also in accordance with the schematic showing of Fig. 2. Hence the voltage unbalancing effect of these reactors is identical with the one described in the foregoing. The premagnetizing control windings 11, 12, 21 and 22, however, are connected and energized in a different manner. The voltage for exciting these control coils is provided by a constant voltage source denoted by DC and by a direct-current pilot generator PG whose armature 31 is mounted on the shaft 30 of the motor HM so that its output voltage is proportional to the motor speed. The field winding 32 of the pilot generator is excited from the voltage source DC through a normally closed switch S2. Another switch S1, series-connected with a discharge resistor R6, is normally open. A poten-

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tiometer resistor R4 is connected across the terminals of the constant voltage source DC and has a number of tap points denoted by P1, P2, P3 and P4. The circuit of the series-connected control coils 11 and 12 appertaining to reactors A1 and A2 respectively are connected at point P6 to the positive pole of the pilot generator and at point P5 to the adjustable contact of the potentiometric resistor R4. A valve V1 consisting, for instance, of a copper oxide or the like dry rectifier is also interposed between points P5 and P6 so that the coils 11 and 12 are energized only when the voltage drop between P5 and P6 has a given direction. Similarly, the coils 21 and 22 of reactors B1 and B2 are connected in series with a valve V2 between the same points P5 and P6. The valve V2 is of opposite polarity as compared with valve V1. Consequently only one of the coil pairs 11, 12 or 21, 22 is energized at a time depending upon the direction of the current flow between points P5 and P6.

The operation of the system just described will be more easily understood from the underlying basic circuit scheme shown in Fig. 7. The voltage source DC is connected across resistor R4 in opposition to the pilot generator PG. Hence, if the voltage drop produced by DC between P3 and P1 is equal and opposite to the voltage drop produced between the same points by the pilot generator PG, no current will flow between points P5 and P6 so that control coils 11, 12, 21 and 22 are deenergized and the appertaining reactors unsaturated. When the movable contact of resistor R4 is shifted to point P2, the potentiometric network becomes unbalanced, so that a current flows from point P5 to P6. This current passes only through the coils 21 and 22 of reactors B1 and B2 because the valve V1 prevents a current flow through the coils 11 and 12 of reactors A1 and A2. When the movable contact is shifted to point P4 of resistor R4, the current flow is in the opposite direction so that only coils 11 and 12 of reactors A1 and A2 are energized. Assuming the movable contact to be at point P3 and the network to be balanced, an increase in the speed of the pilot generator PG, causing a corresponding increase of its output voltage, will also unbalance the network and produce a current flow from P6 to P5 through coils 11 and 12 while a reduction speed of the generator will cause a current flow in the opposite direction through coils 21 and 22. In this manner the control of the reactors is dependent on the setting of the resistor R4 obtained, for instance, by manual control means and also upon the speed of the hoist motor.

Reverting now to the illustration of Fig. 6 and assuming the potentiometric network to be balanced at a selected moment, no current will flow through coils 11, 12, 21 and 22 so that all four reactors are unsaturated and have maximum inductive resistance. The conditions are then in accordance with the diagram of Fig. 3, that is, the motor torque is zero at this moment. If the motor is overhauled so as to cause a voltage to appear across the pilot generator, current will flow from the positive pole of PG to point P6 and thence through coils 12 and 11 and the valve V1 to points P5 and P3. This causes the reactors A1 and A2 to be premagnetized in a degree increasing in proportion to the speed of the motor. As a result the voltage distribution approaches the condition represented in Fig. 5 and produces an increasing motor torque in opposition to the overhauling load. The corresponding speed

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torque conditions are schematically represented in Fig. 9 by curves D1, D2, D3 and D4 corresponding to points P1, P2, P3 and P4, respectively, of the resistor R4 in Fig. 6. Referring, for instance, to curve D3, this speed torque characteristic is obtained when point P5 in Fig. 4 is given the corresponding degree of positive polarity by connecting it with point P3 of resistor R4. Due to this adjustment, the reactors B1 and B2 are premagnetized to a corresponding degree of partial saturation while the hoisting motor is at rest so that a torque in the lowering direction is produced. As the speed rises the pilot generator PG reduces the premagnetization of the reactors B1 and B2, and, when the generator voltage equals the adjusted voltage drop caused by the source DC, the reactors become unsaturated, so that the motor torque decreases to zero at the corresponding speed. If the load is overhauling so that the speed continues to rise, the pilot generator will cause an increase in magnetization of the reactors A1 and A2 thereby producing a rising counter-torque in opposition to the overhauling speed. The curves D2 and D4 are produced similarly by respective lower and higher initial degrees of reactor saturation.

A complete control system designed and operative in accordance with the basic circuit diagram of Fig. 6 is represented in Fig. 8. According to this figure, the line terminals L1, L2 and L3 of the three-phase current supply means are connected with the respective primary motor terminals T1, T2 and T3. The connection between L3 and T3 is fixed while four reactors A1, A2, B1 and B2 are interposed between the other two line terminals and the appertaining motor terminals in the manner described in the foregoing. The hoist motor HM has its armature connected by a suitable mechanical transmission, represented by a shaft 30, with the hoist drum HD and is also in driving connection with the armature 31 of the pilot generator PG. A mechanical friction brake MB is provided for stopping or retarding the hoist drive. This brake has a coil 33 which, when energized, releases the brake in opposition to a biasing spring. The brake coil is connected to a rectifier 34 which, in turn, is energized by a transformer 35 whose primary connections extend over contacts 36 and 37 of a relay BR under control by the appertaining relay coil 38. Two line contactors HC1 and HC2 are provided for controlling the primary motor connections. Contactors HC1 has two contacts 39 and 40 controlled by a coil 41 which, when closed, connect the line terminals L1 and L2 directly to the motor terminals T1 and T2, respectively. Contactor HC2 has three contacts 42, 43 and 44 under control by a coil 45 for connecting the line terminals L1 and L2 with the above-mentioned group of reactors.

A control relay ICR with a contact 46 actuated by a coil 47 is designed as a low-voltage relay. A second control relay denoted by 2CR has contacts 50 and 51 appertaining to the energizing circuit of the premagnetizing reactor windings and actuated by a coil 52. Another control relay marked 3CR and provided with a contact 53 and a coil 54 serves to control the field connection of the pilot generator, and in this respect is similar in function to the switch S2 shown in Fig. 4.

The secondary resistance circuit SRC of the hoist motor HM is controlled by three relays denoted by 1A, 2A and 3A. Relay 1A has four contacts 55, 56, 57 and 58 controlled by a coil

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59, similarly relay 2A has four contacts 65, 66, 67 and 68 under control by a coil 69, while relay 3A has its two contacts 75 and 76 actuated by a coil 74. Three timing relays 1T, 2T and 3T are associated with the secondary control relays in order to provide minimum timing periods between the successive operation of these relays. Each timing relay has a contact 77, 79, or 81 and a control coil 78, 80 or 82.

The above-mentioned relays are connected with a master controller MC which has an off-position, six positions for controlling the hoisting operation of the motor, and five positions for performing lowering operations. A number of inter connected segment groups denoted by 83 through 86 are provided and cooperate with corresponding contact fingers. A number of leads connect the relays with the contact fingers of the master controller and form also a connection between the master controller and the line terminals L1 and L2. Several of these leads are denoted by the numerals 90 through 95.

The system illustrated in Fig. 8 operates as follows: Assuming the line terminals L1, L2 and L3 to be energized by the closure of a main switch (not illustrated), the hoist drive is at rest and the control system deenergized when a master controller MC is in its off-position. In this operating condition the transformer 48 receives current through the circuit L1, 90, 48, 91, 85, 92, L2 so that the rectifier 49 is operative although its secondary circuit is interrupted. The coil 38 of relay BR is deenergized so that contacts 36 and 37 are open. As a result the brake coil 33 is deenergized and hence the friction brake MB set for operation. Immediately upon the closure of the main switch the low-voltage relay ICR picks up because its coil 47 is excited through L1, 90, 93, 47, 85, 92, L2. Relay ICR closes contact 46, thereby sealing itself in. When later the master controller MC is moved out of the off-position, contact 46 maintains coil 47 and the transformer 48 energized as long as no voltage failure occurs. In case of voltage failure relay ICR will drop out and thereby deenergize the control system and set the brake. In order to reset the relay, the master controller MC must first be returned to the off-position.

Assuming the low-voltage relay ICR to remain closed, a lowering operation can be performed by operating the master controller MC as follows:

When placing the master controller on first point lowering the relay BR picks up in circuit L1, 90, 93, 38, 85, 46, 92, L2 and closes contacts 36 and 37, thereby energizing transformer 35 and rectifier 34 for releasing the friction brake MB while placing impressing direct-current voltage across the potentiometric resistor R4. The line contactor HC2 is energized through circuit 93, 45, 85, 46, 92, L2 and connects the line terminals L1 and L2 at contacts 42, 43 and 44 with the motor terminals T1 and T2 through reactors A1, A2, B1 and B2. The circuit connecting point P1 of resistor R4 with point P5 of the premagnetizing control windings of the reactors is closed at segment group 84 of the master controller. As a result the negative potential of point P1 appears at point P5 of the control circuit. Hence current flows from P5 through contact 51, windings 12 and 11 and valve V1 to point P6 and premagnetizes the reactors A2 and A1, while no current can flow from P5 through coils 21 and 22 because of the blocking action of valve V2. Hence reactors B1 and B2 remain unsaturated and the primary voltage is unbalanced and ap-

proaches the conditions represented in Fig. 5. This produces an unbalanced three-phase energization of the motor HM and causes it to develop torque in the lowering direction. As the speed of the motor increases the pilot generator PG increases its bucking effect until the voltage drop between P5 and P6 becomes zero as explained previously. At overhauling loads, reactors B1 and B2 become premagnetized in an increasing degree while reactors A1 and A2 are now unsaturated so that an opposite torque appears tending to decelerate the lowering operation. In this manner the control is self-adjusting so as to obtain a lower speed torque characteristic in accordance with the setting of the master controller, for instance, as represented by curve D1 in the diagram of Fig. 9.

Advancing the master controller to point 2 lowering has the effect of maintaining relays BR and HC2 in the above-mentioned control condition but reduces the effective resistance of control resistor R4 by shorting the resistor portion between points P1 and P2 at segment 84. As a result, the primary voltage effective at the motor terminals is unbalanced to a degree higher than at first point lowering, thus producing a higher torque in the lowering direction and developing a higher lowering speed, for instance, in accordance with the characteristic D2 in Fig. 9.

On third point lowering, the effective resistance of R4 is further reduced by shorting the resistor portion between points P1 and P3 at segment 84 of the master controller. This corresponds to a still greater degree of unbalance and consequently to a higher lowering speed, for instance, as exemplified by the characteristic D3 in Fig. 9.

On fourth point lowering, the portion between points P1 and P4 of resistor R4 is shorted so as to obtain the maximum unbalance of the primary voltage corresponding, for instance, to the characteristic D4 in Fig. 9. As apparent from these speed-torque characteristics, each subsequent lowering point of the master controller requires a higher speed of the motor and pilot generator in order to compensate the effective constant voltage component of the premagnetizing control circuit.

On fifth point lowering, the master controller MC maintains the previous control adjustment of the reactor group but energizes coil 54 of relay 3CR thereby opening, at 53, the field circuit of the pilot generator. This permits attaining maximum lowering speed because the bucking voltage of the pilot generator is reduced to a minimum or zero. The speed torque characteristic thus obtained is typified in Fig. 9 by curve D5.

A hoisting operation can be performed in the following manner: When moving the master controller from off to first point hoist, the line contactor HC2 is picked up by energization of its coil 45 through circuit L1, 90, 45, 85, 46, 92, L2. Hence the reactors A1, A2, B1 and B2 are interposed between the line terminals and the motor by the closure of contacts 42, 43 and 44. In contrast to the above-described lowering operation, the relay 2CR is energized through L1, 90, 52, 85 and remains energized in all subsequent hoisting steps of the master controller. As a result the valve V2 of the premagnetizing control circuit is shorted while the connection between point P5 and the control windings I1 and I2 of reactors A1 and A2 is interrupted at 51. Consequently only the reactors B1 and B2 are in operative condition during all steps of a hoisting performance. This causes an unbalance

of the primary motor voltage which produces a torque in the hoisting direction of the motor. Still referring to first point hoist, point P5 of the control circuit is connected through segment group 83 with point P2 of resistor R4. This corresponds to a relatively low premagnetization of reactors B1 and B2 so that the motor is energized for slow hoisting speed.

On second point hoist, the portion between points P2 and P3 of resistor R4 is shorted and hence the premagnetization increased corresponding to a higher motor speed characteristic. On third point hoist, the resistor portion between P2 and P4 is shorted, thereby changing the motor operation to still another speed torque characteristic for higher speeds.

During first, second and third point hoist, the pilot generator PG is in operation as described in the foregoing so that the speed torque conditions of the motor tend to assume different balance characteristics corresponding to the respective adjustments of the master controller. The characteristic at any selected moment during the automatic control operation lies somewhere in the area denoted by H3 in the diagram of Fig. 9.

On fourth point hoist of the master controller, the line contactor HC2 drops out and the contactor HC1 is energized instead. As a result the reactors A1, A2, B1 and B2 are disconnected and the line terminals L1 and L2 are directly connected to the primary motor terminals T1 and T2 at contacts 40 and 39, respectively. The connection of the potentiometric resistor R4 with point P5 of the control circuit is interrupted at 83 and remains open on the subsequent hoist points. Consequently, the reactor control in this embodiment is inoperative at higher hoisting speeds. Therefore the motor now is energized by a balanced three-phase voltage and develops normal three-phase hoisting torque, for instance, in accordance with the characteristic denoted by H4 in Fig. 9.

On fifth point hoist, the rectifier 49 is connected through sector group 86 to coil 78 of timing relay 1T so that contact 77 is closed. Relay 1A picks up through circuit L1, 90, 59, 77, 85, 46, 92, L2 and shorts part of the secondary resistance circuit SRC at contacts 55 and 56. This corresponds, for instance, to a speed torque characteristic as represented by curve H5 in Fig. 9.

On sixth point hoist, relay 3T is energized and opens contact 81. At the same time coil 69 of relay 2A obtains energization through circuit L1, 90, 57, 69, 79, MC and shorts an increased portion of the secondary resistance circuit SRC by closing the contacts 65 and 66 thus resulting in a speed torque characteristic as shown by curve H6 in Fig. 9. The actuation of relay 2A has also the effect of preparing, at 67, a circuit for the coil 74 of relay 3A and disconnects the coil 82 of relay 3T at 68. Upon elapse of a timing period of relay 3T the contact 81 is closed, thus completing the circuit of coil 74 and causing the relay 3A to close its contacts 75 and 76. In this manner the motor is set for maximum hoisting speed in accordance with curve H6a in Fig. 9, for instance.

While I have illustrated a bridge type network of saturable reactors for distorting the balance of the primary motor voltage in different degrees and different direction, it will be obvious to those in the art that the above-disclosed principles and features of my invention can also be embodied in systems which represent modifications or involve changes as compared with those exemplified in this specification. For

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instance, since each pair of the above-described reactors operates as a unit, these two reactors may be provided with a single magnet core and a single premagnetizing winding. It will also be understood that the underlying potentiometric or autotransformer principle as most simply elucidated by Fig. 2 can also be reduced to practice by other type inductance or resistance devices which permit varying two of the phase voltages relative to the third in order to produce the desired controllable unbalance of the primary multiphase voltage. In view of the possibility of applying such modifications without departing from the essential features, objects and advantages of my invention, I wish this specification to be understood as illustrative but not in a limiting sense.

I claim as my invention:

1. A motor control system comprising a three-phase alternating-current motor having field windings and three primary terminals in fixed connection with one another, three-phase alternating current supply means having three supply leads of which one is in fixed connection with one of said terminals, inductance means interposed between said two other leads and said respective two terminals and operable to unbalance the voltage distribution between said terminals, and speed responsive control means connected between said motor and said inductance means for causing said inductance means to unbalance said voltage distribution in a degree varying substantially in accordance with the motor speed.

2. A motor control system comprising an alternating-current hoist motor having three primary terminals, three-phase circuit means for supplying energizing current to said terminals, adjustable impedance means disposed between said supply means and two of said terminals for unbalancing the phase distribution of said current relative to said terminals and having a range of adjustment including a torque-reversing unbalance adjustment, manual control means connected with said impedance means for controlling their adjustment, and speed responsive automatic control means connected with said impedance means and with said motor for superimposing on the manual control a torque reversing control of said impedance means in dependence upon the motor speed.

3. A motor control system comprising an alternating-current motor having three primary terminals, three-phase current means for supplying energizing current to said terminals, said supply means having three leads of which one is in direct connection with one of said motor terminals, and a bridge-type network having input terminals connected with said other two leads and output terminals connected with said other two motor terminals and containing adjustable inductance means for unbalancing the primary voltage.

4. A motor control system comprising an alternating-current motor having three primary terminals, three-phase current means for supplying energizing circuit to said terminals, said supply means having three leads of which one is in fixed connection with one of said motor terminals, and a bridge-type network having input terminals connected with said other two leads and output terminals connected with said other two motor terminals and containing controllable impedance means for varying the phase distribution of said current, said impedance means having a range of adjustment including that of a substantially balanced distribution and those of two oppositely

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unbalanced and hence torque reversing states of distribution.

5. A hoist control system comprising an alternating-current hoist motor having three primary terminals, three-phase means for supplying energizing current to said terminals, said supply means having three leads of which one is in fixed connection with one of said motor terminals, and a bridge-type network having input terminals connected with said other two leads and output terminals connected with said other two motor terminals and containing adjustable impedance means for varying the ratio of the phase voltages of said motor, said impedance means having a range of adjustment including that of a substantially balanced primary motor voltage and those of two oppositely unbalanced and hence torque reversing voltages, line contactors forming part of said supply means for selectively operating said motor in hoisting and lowering direction, and operator-actuated master control means connected with said contactors and said inductance means for rendering the latter operative when said motor is set for given lowering conditions and inoperative when said motor is set for given other load conditions.

6. A motor control system comprising a three-phase alternating current motor, a three-phase current supply means therefor, a two-phase network of saturable reactors disposed between said supply means and said motor so as to permit varying two of the phase voltages of said motor relative to each other while maintaining the third substantially constant in order to thereby unbalance the three-phase primary voltage of said motor, said reactors having premagnetizing coils, and control means connected to said coils for controlling said reactors.

7. A motor control system comprising an alternating current multiphase hoist motor, multiphase current supply means therefor, saturable reactor means disposed in two phases of said supply means and having respective premagnetizing windings for controlling said reactor means so as to unbalance the multiphase voltage of said motor, and energizing means controlled by said motor and connected with said windings for controlling said reactor means substantially in accordance with the motor speed to produce a torque reversing voltage unbalance under overhauling load conditions of said motor.

8. A hoist control system comprising a three-phase alternating-current motor, three-phase current supply means therefor, saturable reactors arranged in two phases of said supply means, premagnetizing means for adjusting said reactors so as to unbalance the primary voltage of said motor, master control means for selectively setting said motor for hoisting and lowering operation with different speed-torque characteristics, and energizing means for said premagnetizing means connected with said master control means so as to cause said reactors to unbalance said voltage when said motor is set for low-speed lowering.

9. A motor control system comprising an alternating-current motor having multiphase primary terminals, multiphase line terminals for connection to an alternating current source of substantially balanced voltage of given phase rotation, unbalanceable voltage adjusting means disposed between a plurality of said line terminals and a plurality of said motor terminals for unbalancing the multi-phase voltage imposed on said motor terminals and having a range of adjustment

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which includes an adjustment for an unbalanced motor voltage of a phase rotation opposite to that of said source voltage, automatic control means connected with said motor and with said voltage adjusting means for varying the adjustment of the latter substantially in accordance with the motor speed so as to cause said voltage adjusting means to reverse said phase rotation at a given value of motor speed, and selective motor control means connected with said automatic control means for setting said given speed value.

10. A motor control system, comprising a multiphase alternating-current motor, a three-phase energizing circuit connected to said motor, controllable impedance means disposed in a lesser number of phases of said circuit for varying the energy distribution relative to said motor, said impedance means having voltage-responsive control means for controlling the impedance condition of said impedance means, a control circuit connected to said control means, first voltage-supply means of substantially constant voltage connected with said circuit, and second voltage supply means of variable voltage also connected with said circuit so that said control means are controlled by a resultant effect of said two voltages, said second voltage supply means being associated with said motor so that said variable voltage varies substantially in accordance with speed variations of said motor.

11. A motor control system, comprising a multiphase alternating-current motor, a three-phase energizing circuit connected to said motor, controllable impedance means disposed in a lesser number of phases of said circuit for varying the energy distribution relative to said motor, said impedance means having voltage-responsive control means for controlling the impedance condition of said impedance means, a first voltage supply means connected to said control means for providing a substantially constant voltage therefor and including adjustable voltage control means for selectively adjusting the value of said constant voltage, and second voltage supply means having a voltage variable in dependence upon the speed of said motor and being also connected to said control means so that the latter means are subject to a resultant effect of said two voltages.

12. A motor control system, comprising a multiphase alternating-current motor, a three-phase energizing circuit connected to said motor, controllable impedance means disposed in a lesser number of phases of said circuit for varying the energy distribution relative to said motor, said impedance means having voltage-responsive control means for controlling the impedance condition of said impedance means, speed-measuring voltage supply means connected to said control means to provide therefor a voltage variable substantially in accordance with speed variations of said motor, constant-voltage supply means connected to said control means to provide therefor a substantially constant voltage, said two voltage supply means being connected in opposition to each other to jointly control said control means in accordance with the differential value of said two voltages.

13. A motor control system, comprising a multiphase alternating-current motor, a three-phase energizing circuit connected to said motor, controllable impedance means disposed in a lesser number of phases of said circuit for varying the energy distribution relative to said motor, said impedance means having voltage-responsive con-

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trol means for controlling the impedance condition of said impedance means, speed-measuring voltage supply means connected to said control means to provide therefor a voltage variable substantially in accordance with speed variations of said motor, constant-voltage supply means connected to said control means to provide therefor a substantially constant voltage and being disposed in opposition to said speed-measuring voltage supply means so that said control means is controlled in accordance with the differential value of said two voltages, a rheostat forming part of said constant-voltage supply means, and operator-actuable contact means for adjusting said rheostat in order to selectively change the value of said constant voltage.

14. A motor control system, comprising a multiphase alternating-current motor, a multiphase circuit having leads attached to said motor for energizing the latter, a plurality of controllable impedance devices disposed in a lesser number of said leads for varying the energy distribution relative to the phases of said motor, each of said devices having control means for varying the impedance of said respective devices, and a voltage supply means for providing a control voltage variable substantially in accordance with the speed of said motor, and a circuit connecting said voltage supply source means with said plurality of control means for simultaneously controlling said devices.

15. A motor control system, comprising a three-phase alternating-current motor, a three-phase circuit connected to said motor for supplying energy thereto, a plurality of energy control devices disposed in two phases of said circuit for controlling the distribution of said energy relative to said motor, voltage-responsive control means forming part of said respective devices for controlling the latter, voltage supply means for providing a voltage variable substantially in accordance with the speed of said motor and connected to said control means for simultaneously controlling said devices so as to vary said energy distribution in dependence upon the motor speed.

16. A motor control system, comprising a three-phase alternating-current motor having three terminals, three line terminals connected to said respective motor terminals to provide three-phase energy, control means disposed between two of said line terminals and two of said motor terminals for varying the energy distribution relative to said motor terminals and comprising two controllable impedance devices arranged so that the energy flow to one of said two motor terminals increases with decreasing impedance of one of said devices and the energy flow to the other one of said two motor terminals increases with decreasing impedance of said other device, said two devices having control means for controlling said impedance of said respective devices, circuit means connected to said control means for applying variable control voltage thereto so as to selectively increase the impedance of either device depending upon the polarity of said control voltage, first voltage supply means associated with said motor and connected to said circuit means for providing a component voltage variable in accordance with the motor speed, second voltage supply means connected to said circuit means for providing a constant component voltage in opposition to said variable component voltage so that said control voltage corresponds to the differential value of said com-

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ponent voltages, and selectively adjustable means for varying one of said component voltages relative to the other to permit selecting the motor speed at which said control voltage reverses its polarity.

17. A motor control system, comprising a three-phase alternating-current motor, a three-phase circuit connected to said motor for supplying energy thereto, energy control means disposed in said circuit for controlling the phase distribution of said energy, electric circuit means connected with said energy control means, and associated with said motor for controlling said energy control means to vary said phase distribution in dependence upon the motor speed, said electric circuit means having two voltage supply means disposed in mutually opposing relation so

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that the control of said phase distribution is due to differential action of said two voltage supply means.

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