Dec. 11, 1956 M. W. GRIFFES ET AL 2,774,020

OVERDRIVE CONTROL AND BRAKING SYSTEM

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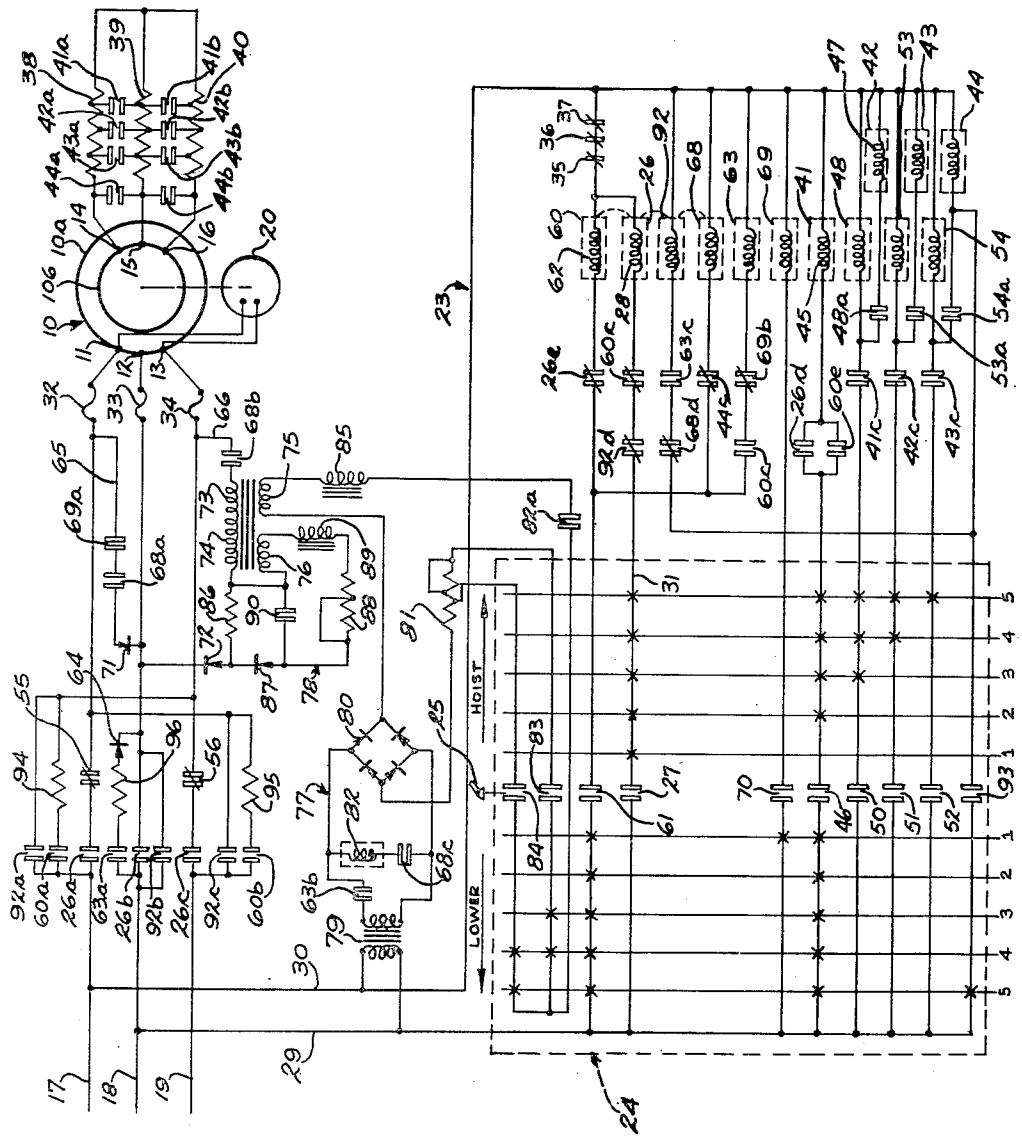

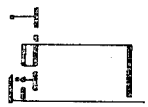

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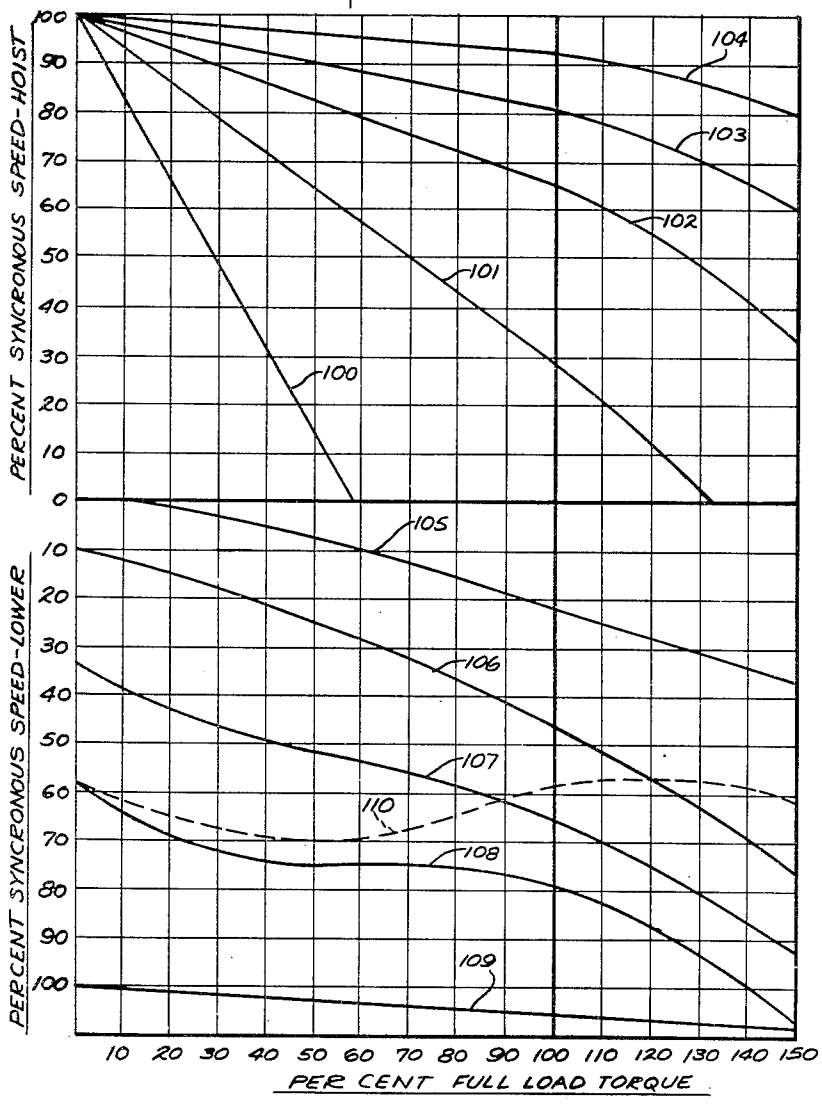
Fig. 2



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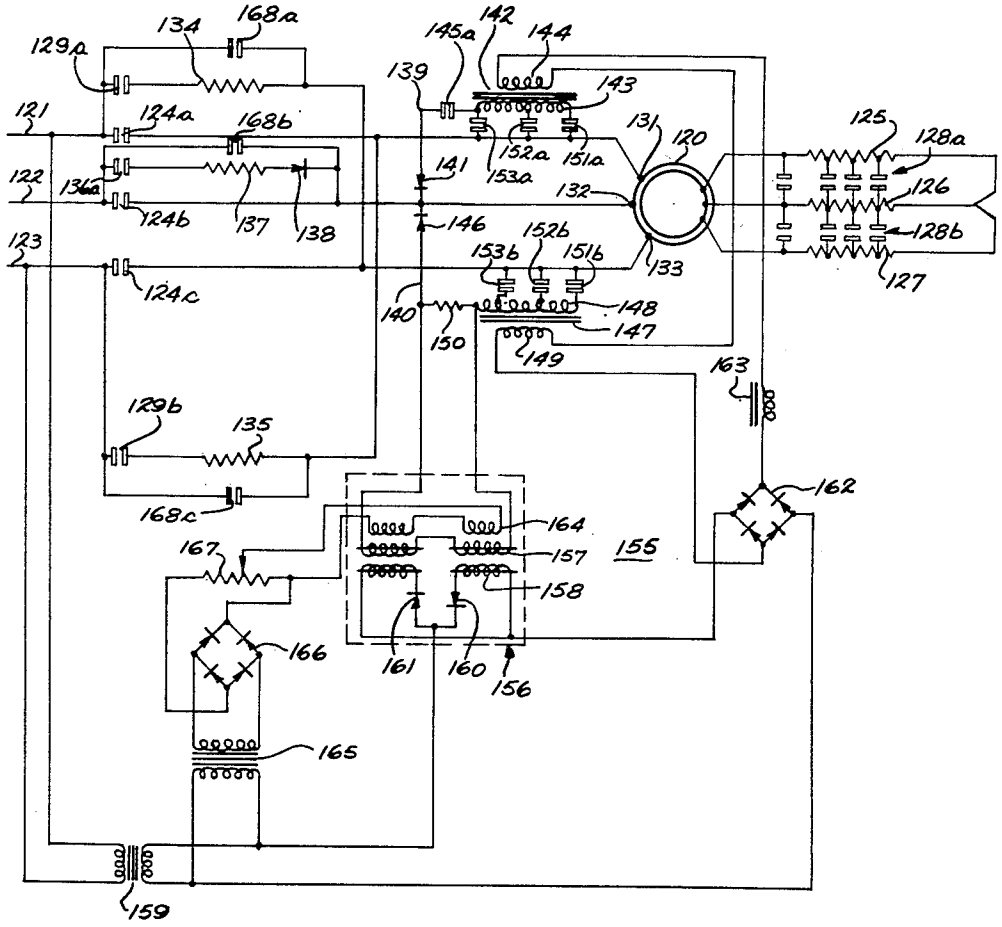

Fig. 3

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OVERDRIVE CONTROL AND BRAKING SYSTEM

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Application August 4, 1954, Serial No. 447,809

11 Claims. (Cl. 318—203)

This invention relates to alternating current electric motor controls and, more particularly, to a control for electric motor drives for crane hoists and the like.

A principal object of the invention is to provide an alternating current crane hoist drive wherein a load of any weight may be raised or lowered at any desired predetermined speed.

Another object of the invention is to provide an alternating current crane hoist drive in which non-overhauling loads may be lowered at any desired predetermined speed and also in which overhauling loads may be lowered at any desired predetermined speed up to the synchronous speed of the motor.

Another object of the invention is to provide an alternating current crane hoist drive in which arbitrary speed-torque characteristics may be obtained for both overhauling and non-overhauling loads during downdrive.

Still another object of the invention is to provide an alternating current crane hoist drive which incorporates power lowering of non-overhauling loads with dynamic braking of overhauling loads.

A further object of the invention is to provide an alternating current crane hoist drive which is self-regulated during lowering operations so as to maintain the lowering speed substantially for downdrive and overhauling loads, whatever the weight of the load.

A still further object of the invention is to obtain arbitrary speed-torque characteristics in wound rotor induction motors.

The art pertaining to crane hoist drives has heretofore encountered serious objections in attempts to use alternating current equipment. The operating conditions imposed upon such equipment particularly where difficult lowering conditions are encountered, as, e. g. where there is a wide variation in the weight of the loads or where the lowering must be done with no-load on the hook at subsynchronous speeds substantially equal to the lowering speeds for heavy overhauling loads, have mitigated against the use of such equipment.

Copending application, Serial No. 430,516, filed May 18, 1954, by Milton W. Griffes, describes a novel and highly advantageous control system whereby a three-phase, alternating current, wound rotor induction motor may be employed for crane hoist drives in such a way as to achieve all the desirable characteristics of direct current drives, but without the use of ancillary braking or load measuring equipment heretofore employed.

The invention of the present application involves a control arrangement for three-phase, alternating current, wound rotor induction motors based upon the apparatus of the application previously referred to. However, the apparatus of the present invention incorporates an arrangement whereby the speed of the drive motor is automatically regulated during lowering drive so as to maintain the motor speed constant within relatively narrow ranges whatever the nature of the load carried by the hoist. That is, the control is such that the hoist apparatus

is driven at substantially the same speed whether the apparatus must be driven downward under no-load conditions; or whether the hoist apparatus carries overhauling loads, so that the drive motor must exert a braking torque in order to control the speed of lowering. Such an arrangement is of particular advantage in the crane art inasmuch as the crane operator is usually provided with a step-type of master controller and the logical relation between the direction and speed of motor drive and the direction and extent of movement of the control largely determines the ease and rapidity of operation of the crane.

In the apparatus of the application referred to above, suitable means were provided for energizing the stator windings of the drive motor to produce a stationary field which would be cut by the windings of the rotor when the rotor was driven by an overhauling load. The apparatus included shunt circuits connected across the stator windings so that the counter-E. M. F's produced in the stator windings by reason of the interaction between the stationary field and the rotor windings produce circulating currents in the windings. The magnitude of the circulating currents determined the amount of braking torque exerted upon the rotor, and adjustment of the braking torque was accomplished by changing the impedance of the shunt circuits, as by utilizing a saturable reactor having tapped windings or auxiliary control windings.

In the present invention, the braking torque is automatically regulated to maintain the speed of the rotor within a predetermined range, whatever the amount of the overhauling load, by controlling the circulating currents in the shunt circuits referred to above. The magnitude of those circulating currents is sensed or determined by means of a sensing resistor connected in the shunt circuit and the voltage developed across the sensing resistor is utilized to operate a control means for changing the impedance of the saturable reactor referred to above.

In a preferred embodiment of the invention, a control rectifier is employed in such a manner that the reactance of the saturable reactor is not affected by circulating currents of less than a predetermined magnitude while, in another embodiment of the invention, the reactance of the reactor is controlled continuously whatever the magnitude of the circulating current. It is an important result of the invention that any of a wide range of lowering characteristics may be obtained by arbitrary selection of the shunt and control circuit parameters.

The invention, together with certain objects, features and advantages thereof, will become more readily apparent from a consideration of the following detailed description and claims taken in connection with the accompanying drawings, in which:

Fig. 1 is a diagrammatic representation of the one embodiment of the invention in schematic aspect;

Fig. 2 is a speed-torque diagram particularly setting forth the drive characteristics of the apparatus of the invention; and

Fig. 3 is a diagrammatic representation of an alternative embodiment of the invention employing a magnetic amplifier for controlling the saturable reactor of the shunt circuits.

Referring now to Fig. 1, a drive motor **10** is a three-phase alternating current motor such as is utilized for driving the hoist machinery of a crane. The motor **10** is a conventional three-phase, wound rotor induction motor having a stator and stator windings, referred to at **10***a*, and winding terminals conventionally represented at **11**, **12** and **13**, and a rotor and rotor windings, referred to at **10***b*, and winding terminals conventionally represented at **14**, **15** and **16**. The motor is energized by the

usual three-phase alternating current power source (not shown), through three main power leads 17, 18 and 19. A single-phase alternating current brake 20 is connected to the power leads 17 and 19 and exerts a holding torque upon the motor shaft. When the motor is energized, the brake is released.

The apparatus of the invention includes stator or primary circuit control apparatus 21 for applying three-phase alternating current voltages to the stator windings during hoisting drive and for interconnecting the apparatus in the primary circuit for lowering drive, as hereinafter described. A rotor or secondary circuit control apparatus 22 includes resistors and contactors for selectively changing the secondary circuit resistance to vary the speed at which the motor operates. A control apparatus 23 incorporates such switches and contactors as are necessary to operate the apparatus of circuits 21 and 22 and perform the necessary switching and other interconnecting operations. In particular, a main switch 24 having a handle 25 is a manually operated rotary sequence switch of a type well known in the art. The handle 25 is adapted to be moved by the crane operator to any one of several positions according to the direction and speed of drive required, e. g. for hoisting the load or lowering the load.

The power leads 17, 18 and 19 are connected to the terminals 11, 12 and 13 for forward or hoisting drive by means of three main contacts 26*a*, 26*b* and 26*c* of a main contactor 26. The contactor 26 is energized by a contact 27 of the master switch 24, connected in series with the solenoid 28 of the contactor switch 26, and a control energizing circuit which includes control power leads 29 and 30 from the main power leads 17 and 18. The main contactor 26 is closed during all hoisting positions of the main switch 24, as is indicated by the crosses at the intersection of the vertical lines indicated as 1, 2, 3, 4 and 5, denoting switch positions, and the lead 31 to the contacts 27.

Three overload relays are provided for interrupting the primary circuit in the event that excessive currents are drawn and have the thermal elements 32, 33 and 34 thereof connected in series with the main power leads 17, 18 and 19 and the normally closed contacts 35, 36 and 37 thereof connected in series with solenoid 28 of the contactor 26.

When the motor 10 is excited for hoisting drive, the speed of the motor is adjusted by changing the amount of resistance in the rotor circuit of the motor. The secondary control apparatus 22 includes three tapped resistors 38, 39 and 40 of a type well known in the motor control art, while a number of magnetic acceleration contactors 41, 42, 43 and 44 have the contacts thereof connected across portions of the resistors so that the resistance of the circuit may be changed by actuating and deactuating the contactors.

A first acceleration contactor 41 has the contacts 41*a* and 41*b* thereof connected to the resistors 38 and 40 and to the resistor 39 for shunting a first portion of the resistors when the contacts are closed. The solenoid 45 of contactor 41 is energized through a contact 46 of the master controller 24 and through the normally open contacts 26*d* of the main contactor 26. The contactor 41 is actuated and the contacts 41*a* and 41*b* closed in the second, third, fourth and fifth hoisting positions of the master controller and, by reason of contacts 26*d*, may only be actuated when the main contactor 26 is in a closed position.

A second acceleration contactor 42 has contacts 42*a* and 42*b* connected to the resistors 38 and 40 and to resistor 39 for shunting a further portion of the resistors from the active circuit when the contacts are closed. The solenoid 47 of the contactor 42 is energized through a contact 48*a* of a time delay relay 48 which is, in turn, energized by a contact 50 of the master controller 24. A normally open contact 41*c* of the first acceleration contactor 41 is connected in series with the contact 50 and the solenoid of the relay 48 and the contact 48*a* and the solenoid of contactor 42 may only be actuated after contactor 41 has been closed. The time delay relay 48 is provided so as to insure an acceleration interval between the closing of contacts 41*a* and 41*b* and contacts 42*a* and 42*b* in the event that the operator moves the handle 25 directly from position 1 to position 3.

In like manner, the third and fourth acceleration contactors 43 and 44 having contacts 43*a* and 43*b* and 44*a* and 44*b* connected to the resistors 38 and 40 and to resistor 39 for shunting further portions of the resistors when the contacts are closed. Contactors 43 and 44 are operatively actuated by contacts 51 and 52 of the master controller 24 and time delay relays 53 and 54, respectively. The time delay relays 53 and 54 have their solenoids connected in series with the normally open contacts 42*c* and 43*c*, respectively, each of the preceding acceleration contactor, so that the time delay relays are energized only after the preceding acceleration contactor has been closed. Relay 44 is energized in the fifth position of the master controller handle and contacts 44*a* and 44*b* are shunted directly across the terminals 14, 15 and 16 of the rotor so that the motor 10 runs at full synchronous speed when these contacts are closed. When the handle 25 is returned to the off position, all contactors are opened and the motor is deenergized.

Two limit switches 55 and 56 are connected in series with the power leads 17 and 19 and are effective to deenergize the motor 10 when the hoist apparatus reaches certain predetermined positions.

For lowering drive, the control apparatus functions to apply single-phase alternating current voltages to the stator terminals 11 and 13 and to apply rectified alternating current voltages to the stator terminal 12, while connecting shunt circuits between the terminals 11 and 12 and between the terminals 13 and 12 after the manner of the apparatus disclosed in the application referred to above. Also, in accordance with the invention, means are provided for regulating the current in the shunt circuits in order to maintain the speed of the motor constant within predetermined limits during downdrive and overhauling drive.

For lowering drive, power leads 17 and 19 are connected to the terminals 11 and 13 by the contacts 60*a* and 60*b* of a second main contactor 60, to excite two of the stator windings in the motor 10 with single-phase alternating current. The contactor 60 is actuated by a contact 61 of the master controller 24 which is connected in series with the solenoid 62 of the contactor 60. A normally closed contact 26*e* of the main contactor 26 and the overload contacts 34, 35 and 36 are also connected in series with the solenoid 62. The contact 61 is closed in all five lowering positions of the handle 25 and contact 26*e* insures that the contactor 60 cannot be actuated until the contactor 26 has been deactuated and the contacts 26*e* returned to their normally closed condition. The currents which result from the application of the single-phase alternating current voltages to terminals 11 and 13 produce stationary fields in the motor 10. The stationary fields induce currents in the rotor windings which, in turn, produce braking torques upon the rotor to control the speed of the motor during lowering drive.

The power lead 18 is connected to the third stator terminal 12 by means of a contact 63*a* of a third contactor 63 which connects a line rectifier 64 in series with that lead to excite all three of the stator windings with rectified alternating current voltages. The solenoid of the contactor 63 is connected to the contact 61 of the master controller 24 through normally open contact 60*c* of the second main contactor 60 so that the contactor 63 may be actuated by the master controller 24 only when the contactor 60 is closed. The rectified alternating current voltages produced by connecting the rectifier 64 between the power lead 18 and the terminal 12, with the leads 17 and 19 connected to the terminals 13 and 11, respectively,

energize the stator windings of the motor **10** to produce an intermittent rotating field and corresponding intermittent driving torque upon the rotor **10***b*. During the times when the rectifier **64** conducts current in the proper relation to the three separate phase voltages, the rotating field is produced, while during the periods when the rectifier **64** is not so conducting current, only the alternating current phase voltages of leads **17** and **19** are applied to the terminals **11** and **13** to produce a single-phase current in the associated windings.

The voltages applied to the stator windings of the motor, whether applied to terminals **11** and **13** only, as when contacts **60***a* and **60***b* are closed, or to terminals **11**, **12** and **13** simultaneously, when contact **63***a* is closed, produce currents in the rotor windings of the motor **10** which, in turn, produce corresponding counter-E. M. F.'s in the stator coils. These counter-E. M. F.'s are employed to generate circulating currents in two shunt circuits **65** and **66** which are connected to the stator terminals **11** and **12** and **13** and **12**, respectively.

The shunt circuits **65** and **66** perform a dual function. First, the high circulating currents which are generated in the stator windings of the motor **10** as a result of the relatively low impedance shunt path through the circuits **65** and **66** produce strong braking forces upon the rotor of the motor. Secondly, by reason of the presence of the rectifiers **71** and **72**, rectified alternating currents flow in two loops, one from lead **17** through shunt circuit **65** to terminal **12** through the associated stator coil to terminal **13** and thence to power lead **19**, and the other from power lead **19** through the shunt circuit **66** to terminal **12** and the associated stator coil to terminal **11** and the power lead **17**. These currents produce stationary fields for producing purely braking torques upon the rotor **10***b* of the motor. It is an important feature of the invention that the use of the rectifier **64** in series with the power lead **18** and the use of the rectifiers **71** and **72** in the shunt circuits **65** and **66** cooperate to prevent short-circuit currents between the power leads **17** and **18** and **18** and **19**, while forming the circuits referred to above.

The two shunt circuits **65** and **66** are connected directly to the terminal **12** of the motor and are connected to the terminals **11** and **13** by the separate contacts of contactors **68** and **69**. Of these contactors, contactor **68** has a contact in each of the shunt circuits, e. g. contacts **68***a* and **68***b*, respectively, for opening and closing both shunt circuits simultaneously. Contactor **68** has its solenoid connected in series with and energized by the contact **61** of the master controller **24** through the normally closed contact **44***c* of acceleration contactor **44**. Contactor **69** has the contact **69***a* only in the shunt circuit **65** to open and close that circuit and has its solenoid connected to and energized by contact **70** of the master controller **24**. Actuation of the contactor **68**, therefore, opens or closes shunt circuits **65** and **66** simultaneously, while actuation of contactor **69** opens or closes only shunt circuit **65**. Contactor **69** is energized and shunt circuit **65** is effective only in the first lowering position of the handle **25**, while contactor **68** is energized and shunt circuit **66** is effective in the first four lowering positions of the handle **25**.

The rectifier **64** is a half-wave selenium rectifier which is connected so that the direction of current flow is from the power lead **18** to the stator terminal **12**. The shunt circuit rectifiers **71** and **72** are also selenium rectifiers connected so that the direction of current is from the terminals **11** and **13** to the terminal **12**. The representation of the rectifiers and the direction of current flow is conventional and other types of rectifiers may be utilized within the spirit of the invention.

The shunt circuit **66** incorporates a reactor **73** which resists the flow of circulating currents between the stator terminals **13** and **12**. The impedance of the reactor tends to limit the amount of circulating current which can flow, and adjustment of the reactor serves to adjust the amount of braking torque which is exerted upon the rotor of the motor **10** at any given speed of rotation. As set forth in the application referred to above, the reactor **73** may be adjusted for different operating or load conditions of the motor.

In accordance with the present invention, the shunt circuit **66** incorporates means for controlling the saturable reactor so that the current in the circuit is regulated to maintain the speed of the motor substantially constant whatever the load. To this end, the saturable reactor **73** has the power winding **74** thereof connected in series with the contact **68***b* and the shunt rectifier **72**, while a bias winding **75** and a control winding **76** are separately energized. The currents in windings **75** and **76** may be changed to change the reactance of the reactor **73** and hence the impedance of the shunt circuit **66**. The bias winding **75** is energized by a bias supply **77**, while the control winding **76** is energized by a sensing control circuit **78**.

The bias supply **77** includes a transformer **79** which is energized from the control supply leads **29** and **30** and a rectifier **80**. A choke **85** is connected in series with the rectifier **80** and the bias winding **75** to smooth the rectified output voltages to substantially direct current and a tapped resistor **81** is provided for selectively adjusting the current through the bias winding **75** as set forth hereinafter.

The bias supply **77** is controlled by a normally open contact **63***b* of the contactor **63** so that the secondary of the transformer **79** is connected to the rectifier only when the contactor **63** is actuated. A time delay relay **82** has a contact **82***a* connected in series with the lead to the bias winding and is energized by the transformer **79** through a pair of normally open contacts **68***c* of contactor **68**. The bias current may be applied to the bias winding **75** only when the contactor **63** is closed and only after the elapse of a predetermined interval after the contactor **68** is closed.

The application of the bias current to the bias winding **75** to control the reactance exhibited by the reactor **73** is controlled by contacts **83** and **84** of the master controller **24**. The contact **83** closes on the third and fourth lowering positions and causes a current flow through the bias winding **75** which is determined by the voltage drop across a portion of resistor **81**. The contact **84** is closed in the fourth and fifth lowering positions and inserts a smaller portion of the resistor **81** in series with the bias supply so as to increase the bias current in the winding **75** and thereby increase the reactance of the primary winding **74** of the reactor **73**. It will be seen that in the fourth lowering position, the impedance of the shunt circuit **66** is higher than in the third lowering position so that the magnitude of the circulating currents is reduced to permit the motor **10** to lower at a greater speed than in the third position.

The bias winding **75** and the bias supply **77** together with the contacts **83** and **84** provide a means for selectively changing the reactance of the reactor **73** which is under the control of the crane operator. The control circuit **78** functions to automatically regulate the reactor **73** so that the impedance of the shunt circuit is automatically varied in accordance with the magnitude of the circulating currents and to maintain the currents at the selected value. To this end, the control circuit includes a sensing resistor **86** which is connected in the shunt circuit **66** in series with the rectifier **72**. A control rectifier **87**, a resistor **88** and a choke **89** are connected in series with the control winding **76** and those components are, in turn, connected across the sensing resistor **86** so that the voltage developed across that resistor by the current flowing in the shunt circuit **66** is impressed upon the control winding **76**. A filter capacitor **90** is connected across the control rectifier **87** and the sensing resistor **86** and together with the choke **89** filters the control voltages so that the current in the control winding is a direct cur-

rent. The resistor 88 may be adjusted so as to vary the amount of current produced in the control winding by the current in the shunt circuit 66. The values of the components of the control circuit, that is the resistance of the resistors 86 and 88 and the inductance of the choke 89, is determined with reference to the characteristics of the control rectifier 87 and the current flowing in the shunt circuit 66. The arrangement is such that the voltage developed across the sensing resistor 86 by the currents normally circulating through the shunt circuit 66 when lowering at relatively light loads as, e. g. on the first through the fourth lowering positions, inclusive, produces no current or very little current in the control winding 76. However, for the higher currents which are developed at greater loads, substantial currents are generated in the control winding 76. This may be accomplished by operating the control rectifier at or below the knee of the rectification curve in the first four lowering positions under light load conditions and beyond that point under heavy load conditions.

The currents which flow in the control winding 76 at the speeds at which the control circuit must be effective must produce substantial changes in the degree of saturation of the core of the reactor 73. To this end, the reactor 73 is formed of a magnetic material which exhibits a so-called square magnetization curve. Such material are well known in the electrical arts.

The embodiment of the invention of Fig. 1 incorporates provisions for lowering at full synchronous speed, that is, with full three-phase alternating current line voltage excitation. The excitation for such drive is provided in the fifth lowering position of the master controller 24 wherein a contact 93 is closed to energize a contactor 92 and close its contacts 92*a*, 92*b* and 92*c*. Contacts 92*a*, 92*b* and 92*c* connect the power leads 17, 18 and 19 to the terminals 13, 12 and 11, respectively, for exciting the motor 10 with the full three-phase line voltage for substantial induction braking, as is well known in the art. Contactor 44 is connected to contact 93 and is energized with contactor 92 to close contacts 44*a* and 44*b* and reduce the secondary circuit resistance to a minimum. This arrangement permits a maximum braking effort for lowering large overhauling loads at full synchronous speed.

Contacts 68*d* and 63*c* of contactors 68 and 63, respectively, are connected in series with contactor 92. Contacts 68*d* are normally closed contacts so that contactor 92 can be actuated only when contactor 68 is deactuated, while contacts 63*c* are normally open contacts so that contactor 92 may be actuated only when contactor 63 is actuated. Contactors 60 and 26, contactors 26 and 92 and contactors 92 and 68, respectively, are mechanically interlocked as well as electrically interlocked to further insure against improper operation of the several contactors. The first mechanical interlocks are represented symbolically and constitute pivoted mechanical members to prevent the one contactor from moving independently from the other.

Contactor 60 is closed in the fifth lowering position of the master controller 24 so that the actuation of contactor 92 and the closing of contacts 92*a* and 92*c* shunts the line dropping resistors 94 and 95. Contact 92*b* shunts the line dropping resistor 96 and the rectifier 64 since contactor 63 remains closed in the fifth lowering position. The line dropping resistors 94, 95 and 96 function to reduce the line voltage applied to the stator terminals 11, 12 and 13 in the first four lowering positions of the master controller 24.

In operation, the crane operator moves the handle 25 in one direction for hoisting drive and in the opposite direction for lowering drive. When the handle 25 is moved to the first hoisting position, the contact 27 is closed and contactor 26 is actuated to close contacts 26*a*, 26*b* and 26*c*. The motor 10 is energized at full line voltage and the brake 20 is released, allowing the motor to run at a speed determined by the secondary circuit resistors 38, 39 and 40. The speed-torque characteristic of the motor for the excitation of the first hoist position is shown in curve 100 of Fig. 2.

When the handle 25 is moved to the second hoist position, contact 27 remains closed and contact 46 is closed to actuate contactor 41. Contact 26*d*, in series with the contactor 41, is closed when contactor 26 is actuated, so that contactor 41 may be closed by contact 46. Contacts 41*a* and 41*b* are closed to shunt portions of the secondary resistors 38, 39 and 40 and allow the motor 10 to run at a higher speed. The speed-torque characteristic of the motor for the excitation of the second hoist position is shown in curve 101 of Fig. 2.

When the handle 25 is moved to the third hoist position, contacts 27 and 46 of the master controller 24 remain closed, while contact 50 is closed to energize time delay relay 48. The contact 41*c* of contactor 41, in series with the time delay relay 48, was closed when the contactor 41 was actuated in the second hoist position, so that, upon the elapse of a predetermined interval after the closing of contact 50, contacts 48*a* of time delay relay 48 will close to actuate the contactor 42. When contactor 42 is actuated, contacts 42*a* and 42*b* are closed to shunt out a further portion of the secondary resistors 38, 39 and 40 and allow the motor 10 to run at a third speed. The speed-torque characteristic of the motor for the excitation of the third hoist position is shown in curve 102 of Fig. 2.

When the handle 25 is moved to the fourth hoist position, contacts 27, 46 and 50 of the master controller 24 remain closed and contact 51 is closed to energize the time delay relay 53. The contact 42*c* of contactor 42, in series with the time delay relay 53, was closed when contactor 42 was actuated so that the contact 53*a* of time delay relay 53 is closed upon the elapse of a predetermined interval after the contact 51 is closed. When contact 53*a* closes, contactor 43 is actuated to close contacts 43*a* and 43*b* and shunt out further portions of the secondary resistors 38, 39 and 40 and allow the motor 10 to run at a fourth speed. The speed-torque characteristic of the motor for the excitation of the fourth hoist position is shown in curve 103 of Fig. 2.

When the handle 25 is moved to the fifth hoist position, contacts 27, 46, 50 and 51 of the master controller 24 remain closed and contact 52 is closed to energize time delay relay 54 through contact 43*c* of contactor 43. Contact 43*c* was closed when contactor 43 was actuated so that contact 54*a* of relay 54 is closed upon the elapse of a predetermined interval after the contact 52 is closed. Thereupon, contactor 44 is actuated and contacts 44*a* and 44*b* are closed to shunt out the remaining portion of the secondary resistors 38, 39 and 40 to allow the motor to run at its highest speed. The speed-torque characteristics of the motor for the excitation of the fifth hoist position is shown in curve 104 of Fig. 2.

When the handle 25 is returned to the off position, the contacts 27, 46, 50, 51 and 52 of controller 24 are opened and the associated contactors referred to above are deenergized. Contacts 26*a*, 26*b* and 26*c* are opened, the motor 10 is deenergized, and the brake 20 is deenergized to hold the shaft of the motor. It is to be noted that, if the crane operator moves the handle 25 directly from the off position into one of the higher speed hoisting positions, the contactors will nevertheless be operated in a fixed sequence and with appropriate time intervals to allow the motor 10 to accelerate properly from one speed to each successive higher speed.

When the handle 25 is moved to the first lowering position, contact 61 is closed to actuate contactor 60 and close contacts 60*a* and 60*b*. When contacts 60*a* and 60*b* are closed, single-phase alternating current is applied to the terminals 13 and 11 through dropping resistors 94 and 95. The brake 20 is released when contacts 60*a* and 60*b* are closed and contact 60*c* is opened

so that the contactor 26 may not be actuated to close contacts 26*a*, 26*b* and 26*c*.

When contact 61 of the master controller 24 is closed, contactor 68 is actuated to close contacts 68*a*, 68*b* and 68*c*. The closure of contact 68*b* is effective to connect the shunt circuit 66 between the terminals 13 and 12.

The contactor 69 is actuated by contact 70 of the master controller 24 at the same time contactor 68 is actuated by the closing of contact 61, and contact 69*a* is closed to connect the shunt circuit 65 between the terminals 11 and 12 of the motor 10. Simultaneously therewith, contact 46 of master controller 24 is closed to actuate the contactor 41 and close contacts 41*a* and 41*b* to shunt a portion of the secondary resistors 38, 39 and 40.

In this first lowering position, the alternating current excitation and the rectified alternating current excitation produced by the two shunt circuits 65 and 66 is effective to permit a full load to be lowered at about 20% of the full motor speed. The speed-torque characteristic of the motor for the first lowering position is shown in curve 105 of Fig. 2.

In the second lowering position, contacts 61 and 46 remain closed and contactors 60, 63 and 41 remain actuated. Contact 70 is opened to deactuate contactor 69 and open contact 69*a* and the shunt circuit 65. Simultaneously, contact 69*b* of contactor 69 is returned to its normally closed position to energize the solenoid of contactor 63 through the contact 61 of the master controller 24 and contact 60*c* of contactor 60, to actuate contactor 63. Upon actuation of contactor 63, contact 63*a* is closed to connect power lead 18 to the motor terminal 12 through the dropping resistor 96 and the rectifier 64. Likewise, contact 63*b* is closed to energize the time delay relay 82 which, in turn, closes the contact 82*a* after the elapse of a predetermined interval of time.

In the second lowering position, single-phase alternating current voltages are applied to terminals 11 and 13 and rectified alternating current voltages are applied to terminal 12 and the shunt circuit 66 between terminals 11 and 12 is closed. This excitation produces a downdrive torque for relatively light loads and a braking torque sufficient to permit a full load to be lowered at 45% of full motor speed. The speed-torque characteristic of the motor for the excitation of the second lowering position is shown in curve 106 of Fig. 2.

In the third lowering position, contacts 61 and 46 remain closed and the associated contactors remain actuated as in the second lowering position. However, contact 83 of the master controller 24 is closed to connect the bias supply 77 to the bias winding 75. The resultant bias current produces an increase in the effective reactance of the primary winding 74 of the reactor 73, thus decreasing the circulating current in the shunt circuit 66 to produce a lesser braking torque upon the rotor of the motor 10. The resultant excitation produces a downdrive torque for relatively light loads and a braking torque sufficient to permit a full load to be lowered at 65% of full motor speed. The speed-torque characteristic of the motor for the excitation of the third lowering position is shown in the curve 107 of Fig. 2.

In the fourth lowering position, the energization of the motor 10 remains the same except that the contact 84 is closed to shunt a portion of the resistor 81 and increase the current in the bias winding 75. This increase in the bias current further increases the effective reactance of the primary winding 73 of the reactor 75 and decreases the current in the shunt circuit 66. This excitation produces a downdrive torque for light loads of approximately 60% of full speed and permits a full load to be lowered at 80% of full motor speed. The speed-torque characteristic of the motor for the excitation of the fourth lowering position is shown in curve 108 of Fig. 2.

In the fifth lowering position, contacts 61 and 46 of the master controller 24 remain closed and contactors 60, 63 and 41 remain actuated. However, contact 93 of the master controller 24 is closed to actuate contactor 44, whereupon the normally closed contact 44*c* in series with the contactor 68 opens to deactuate contactor 68. Upon the deactuation of contactor 68, contact 68*b* opens to open the shunt circuit 66 and contact 68*c* opens to deenergize the time delay relay 82 and open the contacts 82*a* to deenergize the bias winding 75. When contactor 68 is deactuated, contact 68*d* returns to its normally closed position, thus actuating contactor 92 to close contacts 92*a*, 92*b* and 92*c*. As the contacts 92*a*, 92*b* and 92*c* are closed, the line dropping resistors 94 and 95 and the line dropping resistor 96 and rectifier 64 are shunted to apply full line voltage to the motor 10. This excitation produces full braking torque on overhauling loads. The speed-torque characteristic of the motor for the excitation of the fifth lowering position is shown in curve 109 of Fig. 2.

When the handle 25 is returned to the off position, contacts 84, 61, 46 and 93 of switch 24 are opened and the associated contactors referred to above are deenergized. The handle 25 may, of course, be returned from the fifth lowering position to any of the intermediate lowering positions and the contactors will operate in the proper sequence.

It is to be noted that curves 105, 106 and, particularly, curves 107 and 108 have substantial horizontal components, that is, the lowering speed remains relatively constant over a very wide range of loads or load torques. It is an important part of the invention that the control circuit 78 may be so adjusted as to provide a very wide range of lowering drive characteristics. Thus, for example, the control circuit may be made to over-compensate, as shown, for example, in the dotted curve 110, so that the full loads may be lowered at lower speeds in any given lowering position of the master controller than intermediate loads. The requirements of the art are, however, met when the speed of lowering bears a logical relation to the lowering position of the switch handle for a wide range of loads and speeds. Curves 105–108, inclusive, provide very desirable lowering characteristics as compared, for example, with the characteristics heretofore attained by the alternating current drives of the prior art.

The effect of the control circuit in determining the downdrive characteristics under overhauling load will be apparent from a consideration of the middle portion of curves 107 and 108 and particularly of the latter curve. By reason of the fact that the sensing voltage produced across the resistor 86 is directly determined by the magnitude of the current in the shunt circuit 66 and the braking torque exerted upon the rotor is determined by this current, the regulating effect of the control circuits in such that a substantially flat speed-torque characteristic is obtained. That is, the lowering speed is substantially constant whatever the amount of load, and the lowering speed is directly determined by the position of the controller handle 25.

Referring now to Fig. 3, there is shown an alternative embodiment of the invention in which a magnetic amplifier and suitable associated circuits are utilized for controlling the saturable reactors and regulating the shunt circuit currents under downdrive conditions. The representation of the apparatus is in simplified form, it being intended that the apparatus shown be employed with a control apparatus such as the master controller 24 and the associated contactors and control circuit of Fig. 1.

A three-phase alternating current motor 120, similar to the motor 10 of Fig. 1, is supplied from three three-phase alternating current power leads 121, 122 and 123. Three contacts 124*a*, 124*b* and 124*c* of a main power contactor are utilized to connect the power leads directly to the motor 120 for hoisting drive. Three ac-

celeration resistors 125, 126 and 127 in the rotor circuit of the motor 120 and a plurality of acceleration contactors having contacts 128*a* and 128*b* are provided for changing the secondary circuit resistance and the motor speed in the same manner as in the embodiment of Fig. 1.

For lowering drive, two contacts 129*a* and 129*b* of a power contactor are utilized to connect the power leads 123 to two opposed terminals 133 and 131 of the stator windings of the motor 120 through two dropping resistors 134 and 135, respectively. A contact 136*a* of a power contactor associated with the power contactor 129 is utilized to connect the third power lead 122 to the terminal 132 of the motor 120 through a dropping resistor 137 and a line rectifier 138. Actuation of the power contactor 136 in conjunction with the power contactor 129 during lowering drive energizes the motor 120 in such a manner as to produce an intermittent rotating field and a driving torque during the periods when the rectifier 138 is conducting.

Two shunt circuits 139 and 140 corresponding to shunt circuits 65 and 66 in Fig. 1 are connected from terminal 131 to terminal 132 and from terminal 133 to terminal 132, respectively. These shunt circuits function in the same manner as the corresponding shunt circuits in Fig. 1. Actuation of the contactor having contacts 129*a* and 129*b* during downdrive applies alternating current voltages to terminals 131 and 133 to pass alternating currents through the associated windings. The shunt circuits 139 and 140 include rectifiers and rectified alternating currents are passed through windings connected to the terminals referred to above to produce stationary fields in the motor.

The shunt circuit 139 incorporates a rectifier 141 and a saturable reactor 142 having a power winding 143 and a control winding 144 for changing the apparent reactance of the power winding 143. A contact 145*a* of another power contactor corresponds to the contact 69*a* of Fig. 1 and provides a separate control for opening and closing the shunt circuit 139 independently of the shunt circuit 140.

The shunt circuit 140 includes a rectifier 146 and a saturable reactor 147 having a power winding 148 and a control winding 149, and a sensing resistor 150 corresponding to the sensing resistor 86 of the embodiment of Fig. 1. Portions of the power windings 143 and 148 of the saturable reactors 142 and 147 may be selectively inserted and removed from the corresponding shunt circuits by means of a plurality of power contactors having contacts 151*a* and 151*b*, 152*a* and 152*b* and 153*a* and 153*b* in an arrangement similar to that of the application referred to above.

The control windings 144 and 149 of the reactors 142 and 147 are energized with direct current by means of an electric circuit 155 which is controlled by the sensing resistor 150. The circuit 155 includes a magnetic amplifier 156 which has the primary windings 157 thereof connected to the sensing resistor 150. The secondary windings 158 are energized from a power transformer 159 through two series connected rectifiers 160 and 161 and are connected with the transformer 159 to a bridge rectifier 162. The voltages from the rectifier 162 are utilized to produce appropriate currents in the windings 144 and 149, which are connected in series across the output of the rectifier 162. A choke coil 163 serves to isolate the rectifier 162 and the windings 158 from the windings 144 and 149 and prevent any reaction between those windings. The bias winding 164 of the magnetic amplifier 156 is energized by means of a bias supply including a transformer 165, a bridge rectifier 166, and the current in the bias windings 164 is adjustable by a potentiometer 167.

The magnetic amplifier 156 produces an output voltage which is a function of the voltage developed across the sensing resistor 150 by the circulating current in the shunt circuit 140. This output voltage may be a continuous function of the magnitude of the circulating current, e. g. an output voltage developed for every value of the circulating current or, alternately, the output voltage may be generated only after the circulating current exceeds a predetermined intensity after the fashion of the control circuit of Fig. 1.

The embodiment of the invention of Fig. 3 is particularly useful under circumstances wherein the shunt reactors 143 and 147 do not have good self-saturating characteristics, e. g. are not sensitive to small changes in current magnitudes such as may be produced by the winding 76 of Fig. 1, referred to in columns 6 and 7 of the specification. The magnetic amplifier 156 serves effectively to produce a larger current change than is available by reason of the variations in voltage produced across the sensing resistor 150 alone.

The motor 10 is a three-phase alternating current, wound rotor induction motor. The representation of Fig. 1 is intended to mean that the windings of the motor are Y-connected, that is, so that each of the terminals represented at 11, 12 and 13, constitutes the terminus of a stator winding, while each of the terminals represented at 14, 15 and 16 constitutes the terminus of a rotor winding. However, the invention is not necessarily limited to such an arrangement, and the various windings may be arranged in a so-called delta-connection or in a suitable combination of Y- and delta-connections. No limitation as to the structure of the motor is intended by the employment of such terms as "rotor" and "stator" herein.

It is to be understood that the specific nature of the present disclosure is not intended to be restrictive or confining but that various rearrangements of the apparatus may be resorted to, giving effect to a reasonable breadth of construction of the express language of the claims, as hereinafter set forth.

What is claimed is:

1. Alternating current hoist apparatus comprising, in combination, a three-phase, wound rotor induction motor having rotor windings and three rotor terminals therefor and stator windings and three stator terminals therefor, three three-phase alternating current power leads, means for connecting two of the power leads directly to two of the stator terminals to apply alternating current voltages to those terminals, a line rectifier, and means for connecting the said line rectifier from the third power lead to the third stator terminal of the motor to apply rectified alternating current voltages to the stator windings, a shunt circuit, and means for connecting the said shunt circuit to one of the said two stator terminals and to the third stator terminal for producing circulating currents in the stator windings, the said shunt circuit including a series rectifier connected in opposition to the first-named rectifier for maintaining high impedance paths between the power leads, and passing rectified alternating currents through the stator winding connected to the remaining one of the said two stator terminals, and means for automatically regulating the currents in the shunt circuit to produce a braking torque which is a function of the speed of the motor.

2. Alternating current hoist apparatus comprising, in combination, a three-phase, wound rotor induction motor having rotor windings and three rotor terminals therefor and stator windings and three stator terminals therefor, three three-phase alternating current power leads, means for connecting two of the power leads directly to two of the stator terminals to apply alternating current voltages to those terminals, a line rectifier and means for connecting the said line rectifier from the third power lead to the third stator terminal of the motor to apply rectified alternating current voltages to the stator windings, a shunt circuit, and means for connecting the said

shunt circuit to one of the said two stator terminals and to the third stator terminal for producing circulating currents in the stator windings, the said shunt circuit including a series rectifier connected in opposition to the first-named rectifier for maintaining high impedance paths between the power leads, and passing rectified alternating currents through the stator winding connected to the remaining one of the said two stator terminals, and means for automatically regulating the currents in the shunt circuit comprising a saturable reactor in the shunt circuit, and means responsive to the current in the shunt circuit for changing the degree of saturation of the reactor so as to produce a braking torque which is a function of the speed of the motor, and thereby maintain the lowering speed sensibly constant during overdrive conditions.

3. Alternating current hoist apparatus comprising, in combination, a three-phase, wound rotor, induction motor having rotor windings and three rotor terminals therefor and stator windings and three stator terminals therefor, three three-phase alternating current power leads, means for connecting two of the power leads directly to two of the stator terminals to apply alternating current voltages to those terminals, a line rectifier and means for connecting the said line rectifier from the third power lead to the third stator terminal of the motor to apply recified alternating current voltages to the stator windings, a shunt circuit, and means for connecting the said shunt circuit to one of the said two stator terminals and to the third stator terminal for producing circulating currents in the stator windings, the said shunt circuit including a series rectifier connected in opposition to the first-named rectifier for maintaining high impedance paths between the power leads, and passing rectified alternating currents through the stator winding connected to the remaining one of the said two stator terminals, and means comprising a saturable reactor in the shunt circuit and a sensing resistor in series therewith, a control winding in the said reactor, a control rectifier, and a series connection from the sensing resistor through the control winding and the control rectifier and back to the sensing resistor for changing the degree of saturation of the reactor and regulating the current in the shunt circuit when the current exceeds a predetermined value and thereby maintain the speed of the motor sensibly constant.

4. Alternating current hoist apparatus comprising, in combination, a three-phase, wound rotor induction motor having rotor windings and three rotor terminals therefor and stator windings and three stator terminals therefor, three three-phase alternating current power leads, means for connecting two of the power leads directly to two of the stator terminals to apply alternating current voltages to those terminals, a line rectifier and means for connecting the said line rectifier from the third power lead to the third stator terminal of the motor to apply rectified alternating current voltages to the stator windings, a shunt circuit, and means for connecting the said shunt circuit to one of the said two stator terminals and to the third stator terminal for producing circulating currents in the stator windings, the said shunt circuit including a series rectifier connected in opposition to the first-named rectifier for maintaining high impedance paths between the power leads, and passing rectified alternating currents through the stator winding connected to the remaining one of the said two stator terminals, and means comprising a sturable reactor in the shunt circuit and a sensing resistor in series therewith, a control winding in the said reactor, a magnetic amplifier having the input thereof connected to the sensing resistor and the output thereof connected to the control winding for changing the degree of saturation of the reactor and regulating the current in the shunt circuit when the current exceeds a predetermined value and thereby maintain the speed of the motor sensibly constant.

5. Alternating current hoist apparatus comprising, in combination, a three-phase, wound rotor induction motor having rotor windings and three rotor terminals therefor and stator windings and three stator terminals therefor, three three-phase alternating current power leads, means for connecting two of the power leads directly to two of the stator terminals to apply alternating current voltages to those terminals, a line rectifier and means for connecting the said line rectifier from the third power lead to the third stator terminal of the motor to apply rectified alternating current voltages to the stator windings, a shunt circuit, and means for connecting the said shunt circuit to one of the said two stator terminals and to the third stator terminal for producing circulating currents in the stator windings, the said shunt circuit including a series rectifier connected in opposition to the first-named rectifier for maintaining high impedance paths between the power leads, and passing rectified alternating currents through the stator winding connected to the remaining one of the said two stator terminals, and means comprising a saturable reactor in the shunt circuit and a sensing resistor in series therewith, a control winding in the said reactor, a control rectifier, and a series connection from the sensing resistor through the control winding and the control rectifier and back to the sensing resistor for changing the degree of saturation of the reactor and regulating the current in the shunt circuit when the current exceeds a predetermined value and thereby maintain the speed of the motor sensibly constant, a bias winding and direct current supply means connected to the said bias winding, and means for selectively adjusting the direct current in the bias winding for adjusting the lowering speed of the motor.

6. Alternating current hoist apparatus comprising, in combination, a three-phase, wound rotor induction motor having rotor windings and three rotor terminals therefor, and stator windings and three stator terminals therefor, secondary resistors connected to the three rotor terminals, three three-phase alternating current power leads, means for connecting the said power leads directly to the three stator terminals for hoisting drive, means for connecting two of the power leads to two of the stator terminals to apply alternating current voltages to those terminals, a line rectifier and means for connecting the said line rectifier from the third power lead to the third stator terminal of the motor to apply rectified alternating current voltages to the stator windings, a shunt circuit, and means for connecting the said shunt circuit to one of the said two stator terminals and to the third stator terminal for producing circulaing currents in the stator windings, the said shunt circuit including a series rectifier connected in opposition to the line rectifier for maintaining high impedance paths between the power leads, and passing rectified alternating currents through the stator winding connected to the remaining one of the said two stator terminals, and means in the shunt circuit for automatically regulating the currents in the shunt circuit to produce a braking torque which is a function of the speed of the motor, and thereby maintain the lowering speed sensibly constant.

7. Alternating current hoist apparatus comprising, in combination, a three-phase, wound rotor induction motor having rotor windings and three rotor terminals therefor, and stator windings and three stator terminals therefor, secondary resistors connected to the three rotor terminals, three three-phase alternating current power leads, means for connecting the said power leads directly to the three stator terminals for hoisting drive, means for connecting two of the power leads to two of the stator terminals to apply alternating current voltages to those terminals, a line rectifier and means for connecting the said line rectifier from the third power lead to the third stator terminal of the motor to apply rectified alternating current voltages to the stator windings, a shunt circuit, and means for connecting the said shunt circuit to one of the said two stator terminals and to the third stator terminal for producing

circulating currents in the stator windings, the said shunt circuit including a series rectifier connected in opposition to the line rectifier for maintaining high impedance paths between the power leads, and passing rectified alternating currents through the stator winding connected to the remaining one of the said two stator terminals, and means in the shunt circuit for automatically regulating the currents in the shunt circuit to produce a braking torque which is a function of the speed of the motor and thereby maintain the lowering speed sensibly constant, comprising a saturable reactor in the shunt circuit and a sensing resistor in series therewith, a control winding in the said reactor and electric circuit means for energizing the control winding in accordance with the voltage developed across the sensing resistor by the circulating current.

8. The invention in accordance with claim 7, including a second similar shunt circuit and means for selectively connecting the second shunt circuit to the remaining one of the said two stator terminals and to the third stator terminal.

9. The invention in accordance with claim 7, and including a second similar shunt circuit and means for selectively connecting the second shunt circuit to the remaining one of the said two stator terminals and to the third stator terminal and connections from the said electric circuit means to the control winding of the reactor of the second shunt circuit.

10. Apparatus for controlling a multi-phase alternating current motor having two or more stator windings and three or more power leads comprising, in combination, a line rectifier adapted to be connected in series with a common one of the leads for applying a rectified alternating current voltage to both windings and a shunt circuit adapted to be connected across one of the windings of the motor including a rectifier for energizing the remaining one of the said two windings with rectified alternating current and for circulating currents through the said first winding, a saturable reactor connected in series with the shunt circuit for limiting the current therein, and a sensing resistor connected in series with the reactor and the rectifier, a control winding in the reactor, a control rectifier and a series connection from the sensing resistor through the control winding, the control rectifier and back to the sensing resistor for automatically regulating the circulating current when the magnitude of the circulating current exceeds a predetermined value to thereby maintain the speed of the motor sensibly constant under overdrive conditions.

11. The invention in accordance with claim 10 and including a plurality of magnetic contactors for selectively energizing the motor with alternating current voltages and selectively connecting the said line rectifier and shunt circuits to the motor, and a master controller for operatively actuating the said magnetic contactors.

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