

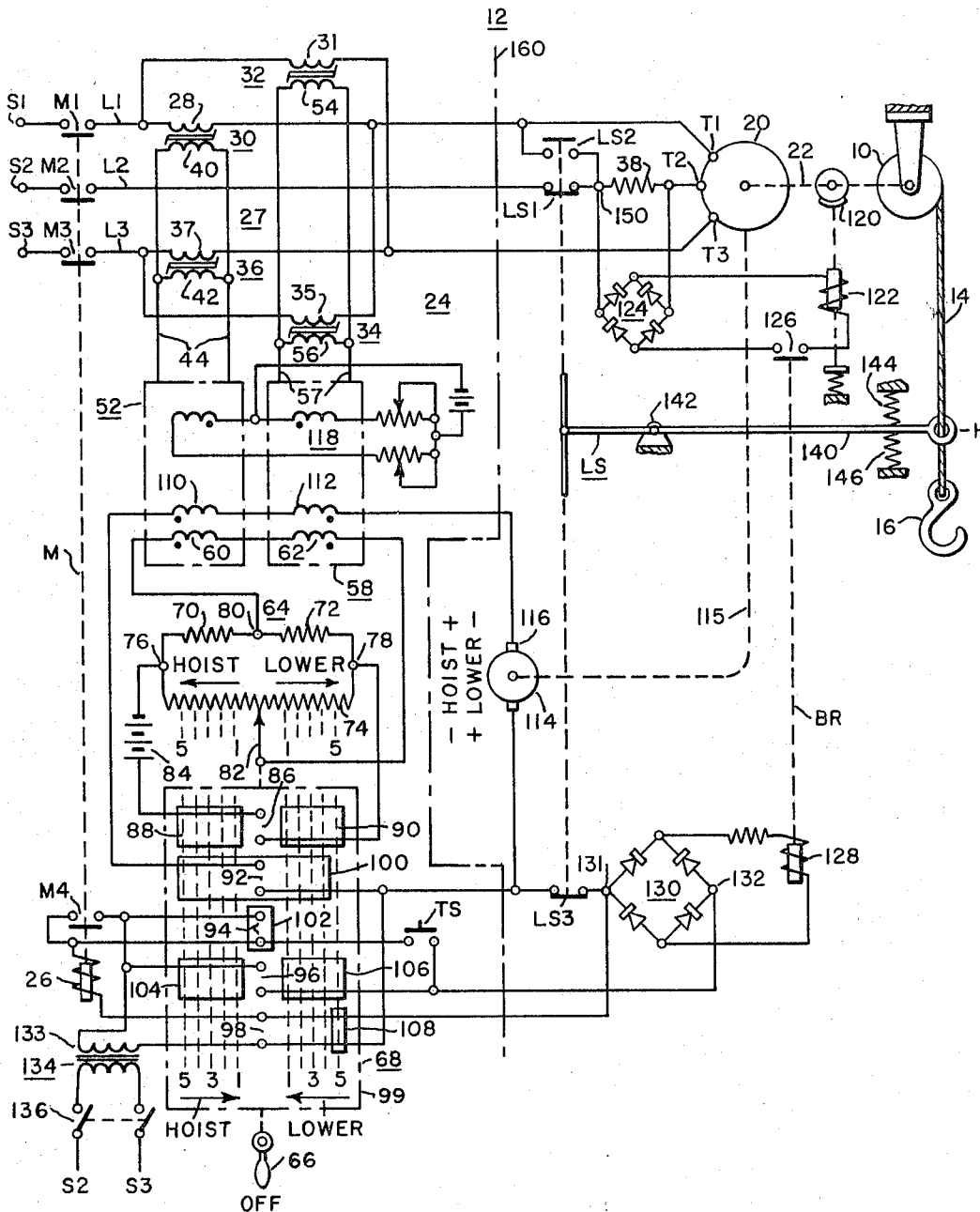
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CONTROLLED BRAKING SYSTEM FOR LOAD LIFTING APPARATUS

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WITNESSES

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CONTROLLED BRAKING SYSTEM FOR LOAD LIFTING APPARATUS

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1 Claim. (Cl. 318—203)

This invention relates to control systems for A.C. (alternating current) powered load lifting apparatus for example cranes, hoists, etc., and more particularly to safety features for such systems.

Industrial cranes are generally provided with releasable electromagnetic brakes which are biased set to brake the load lifting apparatus unless the brake is released by energizing a brake release circuit. When the crane controller is in the OFF position the brake is set, and is released when the crane controller is moved to either HOIST or LOWERING positions. It is customary to provide an upper limit switch which in response to the load lifting apparatus rising above a predetermined limit deenergizes the brake release circuit thereby setting the brake. Electromagnetic brake release circuits are subject to inherent delays and if the limit switch fails to deenergize the brake release circuit, the brake remains released and serious damage can occur.

When "backing out" of an upper limit switch, previous systems release the brake in response to the crane controller being moved to the first point LOWERING (lowest speed lowering) position. This can be disastrous with a heavy load on the hook, since the field excitation applied to the hoist motor at this control position is too low to provide effective dynamic braking.

It is therefore an object of the present invention to provide a new and useful control circuit for A.C.-powered load lifting apparatus.

Another object is to provide in an A.C.-powered load lifting system alternative A.C. dynamic braking control, effective in the region above the upper limit switch, which braking is effective in both hoist and lowering modes of the system.

Another object is to provide a load lifting system which cannot be backed out of an upper limit switch until the controller is moved to a high speed LOWERING position.

A further object is to provide even greater motor excitation and increased dynamic braking in the lowering direction by opening a speed feedback loop in response to the crane controller being moved to the high point LOWERING position.

Yet another object is to provide a load lifting drive having fail-safe braking features in the region above the upper limit switch.

In accordance with one embodiment of the invention the above and other objects of the invention are realized in a three-phase motor driven reversible hoist system having a limit switch, which when tripped in the up direction opens a phase line and establishes an unbalanced single phase circuit to the motor through the remaining two phase lines to provide dynamic braking in either the hoist or lowering direction while the hoist is "above" the limit switch. A further feature of the invention does not allow the crane to be backed out of the limit switch until the crane controller is moved to the high point LOWERING position. In response to the latter position a spring-set brake on the hoist motor is released, and in accordance with a further feature of the invention a speed feedback circuit is disabled to provide increased motor excitation and greater dynamic braking in the LOWERING direction.

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Other and further objects of the invention will become apparent from the following detailed description taken in connection with the single figure drawing wherein a preferred embodiment of the invention is illustrated in connection with a hoist system. In order to simplify the illustration of the invention, auxiliary equipment, such as breakers, relays, electrical interlocks, etc. well known in the art and usually found in apparatus of the character described is not shown.

As seen in the drawing, the diagrammatic representation of a hoist system shown therein includes a hoist drum 10 driven by a reversible drive 12. Reeled around the drum is a load lifting cable 14 with a load hook 16 attached to the free end thereof. The drive 12 includes a three-phase induction motor 20 which drives the drum 10 through a coupling 22, and a control system 24 for controlling the speed and direction of the motor and thereby of the load, by controlling the electric power supplied from a suitable source to the motor. By way of example, the motor 20 is shown as a squirrel cage induction motor supplied from phase-to-phase supply lines L1, L2 and L3 connectable to the terminals S1, S2 and S3 of a source of three-phase power (not shown) through contacts M1, M2 and M3 of a main contactor M when its operating coil 26 is energized. Contacts M1, M2 and M3 are normally open.

The control system 24 includes a voltage adjusting arrangement 27 interposed in the supply lines to the motor and controlled in response to a desired load speed reference signal and an actual load speed feedback signal. These signals are applied as hereinafter described in the input circuits of "hoist" and "lowering" amplifiers, which control the voltage adjusting arrangement 27 to provide speed and reversing control.

More specifically, power line L1 is connected through the main winding 28 of a saturable reactor 30 to a terminal T1 of the motor. Line L1 is also connected through the main winding 31 of a saturable reactor 32 to a terminal T3 of motor 20. In like manner, line L3 is connected to terminals T1 and T3 through the main windings 35 and 37 of saturable reactors 34 and 36, respectively. For convenience, reactors 30 and 36 will be referred to as the "hoist" reactors while reactors 32 and 34 will be referred to as the "lowering" reactors. Line L2 is connected to terminal T2 through normally closed contacts LS1 and a resistor 38.

Contacts LS1 are part of a limit switch LS which is operable in a first mode in response to the hook 16 being below a predetermined height, and in a second mode in response to the hook being above the predetermined height. The first mode of the limit switch LS may be considered its normal mode of operation. Contacts LS1 are closed when the limit switch is in its first or normal mode. The limit switch LS also includes later discussed normally open contacts LS2 and normally closed contacts LS3.

The hoist reactors 30 and 36 are provided with control windings 40 and 42, respectively, which are connected together to the D.C. (direct current) output 44 of a magnetic amplifier 52, which is conveniently referred to as the "hoist" amplifier. Likewise, lowering reactors 32 and 34 have control windings 54 and 56 which are connected together to the D.C. output 57 of a magnetic amplifier 58, which is conveniently referred to as the "lowering" amplifier. It should be apparent that the "hoist" reactors are driven in unison in the same direction by the hoist amplifier 52, either up or down, and that the lowering reactors are driven together in the same direction, either up or down, by the lowering amplifier 58.

Amplifiers 52 and 58 are provided with control windings 60 and 62, respectively, connected in series opposition so that a common signal flowing through these con-

trol windings affects the amplifiers in opposite sense. More specifically, a common control signal through the control windings 60 and 62 will tend to drive the amplifiers 52 and 58 in opposite directions, that is, drive one up while the other is driven down or further into cutoff as the case may be. These windings are connected to a speed voltage source 64 which is selectively adjustable in voltage and polarity in response to the movement of a manual control handle 66 of a master controller 68.

The speed reference source 64 includes resistors 70 and 72 and a potentiometer 74 connected in a Wheatstone bridge arrangement having input terminals at 76 and 78 and output terminals at 80 and the variable contact arm 82 of the potentiometer 74. D.C. (direct current) input voltage is supplied to this bridge arrangement from a suitable D.C. source such as the battery 84 when a pair of normally open contacts 86 are closed by conductive segments 88 and 90 of the controller 68. This occurs whenever the controller handle 66 is moved to any of the indicated HOIST or LOWER positions.

It may be noted at this point that the controller 68 includes a plurality of sets of contact fingers 86, 92, 94, 96 and 98, and a rotatable drum 99 carrying a plurality of contact segments 88, 90, 100, 102, 104, 106 and 108, for bridging the sets of contact fingers in various patterns dictated by various selectable positions of the drum 99 as selected by the control lever 66 which is coupled to drive the drum 99 and the potentiometer arm 82. Five selectable HOIST positions of the drum are defined by the dashed lines labeled 1-5 and located over the HOIST arrow adjacent the lever 66. Likewise five selectable LOWERING positions of the drum are defined by the dashed lines labeled 1-5 and located over the LOWERING arrow adjacent the lever 66. Each of these lines defines a particular position wherein the elements of the drum on this line are aligned with the line of contact fingers.

Controller 68 is so coupled to potentiometer arm 82 that as the controller drum is rotated from the OFF position through HOIST points 1, 2, 3, 4 and 5, a progressively higher speed reference voltage in the hoist direction is supplied by the speed reference source 64 to the control windings 60 and 62. Likewise, as the controller drum is rotated from the OFF position through LOWERING positions 1, 2, 3, 4 and 5 the reference source 64 supplies a progressively higher speed reference voltage in the lowering direction to the control windings 60 and 62.

Amplifiers 52 and 58 are also provided with feedback control windings 110 and 112, respectively, connected in series opposition so that a common signal flowing through these control windings affects the amplifiers in opposite sense.

These windings are supplied with a feedback voltage responsive to the actual speeds of the motor 20 and drum 10 by a tachometer generator 114 driven by the motor 20 through a coupling 115. The feedback loop from the tachometer generator includes a pair of contact fingers 92 which are bridged by conductive segment 100 in all positions of the controller excepting the 5th point LOWERING position. The tachometer 114 provides an output voltage with a magnitude proportional to the motor speed and a plurality dependent on the direction of motor rotation. In the particular arrangement shown, and as indicated by the legends alongside the tachometer, the tachometer generates a positive voltage at its output terminal 116 when the hoist motor 20 is hoisting, and a negative voltage at terminal 116 when the hoist motor is lowering.

The system thus far described constitutes a speed regulated system, i.e., the load speed for any given command or reference speed is maintained constant during hoist operation and all lowering points except the 5th point lowering.

A bias circuit 118 is arranged to bias the HOIST and LOWERING amplifiers 52 and 58 to cutoff at quiescent (no input signals present). Thus, with no signal in any of the control windings, the respective amplifiers 52 and 58 do not produce an output, and the hoist and lowering reactors will be unsaturated, each presenting maximum impedance in its line. The polarity dot convention employed in the drawing in connection with the HOIST and LOWERING amplifiers signifies that a signal of positive polarity applied at the dotted end of the winding will tend to drive the associated amplifier up, the converse being true when a signal of negative polarity is applied to the dotted end of a winding.

When the net control ampere-turns supplied by windings 60 and 110 are in a direction driving the output of amplifier 52 upward, the net control ampere-turns supplied by windings 62 and 112 of amplifier 58 will tend to drive this amplifier downward or further into cutoff. This saturates the hoisting reactors 30 and 36, while the lowering reactors 32 and 34 remain unsaturated. Thus the impedances of reactors 30 and 36 are reduced, thereby effectively connecting line L1 to terminal T1 and line L3 to terminal T3, thereby providing a particular phase rotation to drive the hoist motor 20 in the direction. In the meantime reactors 32 and 34 remain at their maximum impedance, and as a result the circuits from line L1 to terminal T3 and from line L3 to terminal T1 are substantially open circuits.

On the other hand, if the net ampere-turns provided by control windings 62 and 112 are in a direction to drive the output of the lowering amplifier 58 up, then the control ampere-turns supplied to the hoist amplifier 52 will be in a direction tending to drive this amplifier down and hold it to no output. These conditions saturate the LOWERING reactors 32 and 34 while the HOIST reactors 30 and 36 remain unsaturated. As a result line L1 is effectively connected to terminal T3 of the hoist motor 20, and line T3 is effectively connected to terminal T1 of the motor, thereby producing a reversed phase rotation to drive the hoist motor in the lowering direction.

Additionally, the saturation of the HOIST and LOWERING reactors may be controlled to effect a variation between minimum and maximum values of impedance, thereby controlling the motor torque and speed in the chosen direction by varying its primary excitation voltage.

The circuit thus far described constitutes a speed regulated hoist system wherein the load speed for any given command or selected reference speed is maintained constant during hoist operation and all lowering points except 5th point LOWERING. The operation of this portion of the system will now be briefly described.

The command or desired speed reference signal from the speed reference source 64, for any given selected direction is opposed in the input of the amplifiers 52 and 58 by the actual motor speed signal produced by the tachometer 114 when the motor is running in the selected direction. Each of the amplifiers 52 and 58 respond to the differential between the reference and feedback signals which is the regulating "error" in the system. The magnitude and polarity of the selected reference signal from the reference source 64 is dependent on the desired speed and direction selected by positioning the controller lever 66. The magnitude and polarity of the tachometer 114 output is dependent on the speed and direction of the motor 20.

To raise the load hook 16, the master control handle 66 is moved into the HOIST sector of the controller range to a selected position corresponding to the desired speed. Movement of the lever 66 into the HOIST sector, moves the switch drum 99 and the potentiometer arm 82 in unison to their respective HOIST sectors. In the HOIST area, contact arm 82 taps into the negative side of the potentiometer to provide a positive signal to the dot end of winding 60. This drives the output of the hoist amplifier 52 upward to saturate the hoist reactors 30 and 36.

Since a signal of this polarity tends to drive the lowering amplifier down, this amplifier is held at cutoff and the lowering reactors 32 and 34 remain unsaturated and at maximum impedance. The hoist reactor 30 and 36 are saturated to a degree dependent on the magnitude of the command or selected reference signal. As a result, the primary of motor 20 is excited in the proper sense or phase sequence to rotate in the hoist direction. As the speed of the hoist motor increases, the output voltage of the tachometer 114, which is opposed in the input of amplifier 52 by the speed reference signal, increases until equilibrium is reached wherein enough excitation is supplied to the motor to produce the requisite torque to maintain the selected command speed.

If for any reason, the motor 20 should run faster than the selected speed, the tachometer 114 output will override the hoist reference signal, and the resulting error signal in the amplifier inputs will be such as to drive the hoist reactors down and the lowering reactors up. The net result of this is a reversal of the phase sequence applied to the motor and a consequent application of counter torque within the motor or "plugging," thus, slowing the motor down until equilibrium is reached at the proper speed and torque.

To lower the load, the speed reference voltage is reversed in polarity by moving the master control handle 66 to the LOWERING sector, thus moving the potentiometer arm 82 to the LOWERING area of the potentiometer to produce a positive signal at the dot end of control winding 62 and a negative signal at the dot end of control winding 60, thereby driving the output of the lowering amplifier 58 upward to produce the proper sense or phase sequence of the primary excitation applied to the motor 20 input terminals to rotate the motor in the lowering direction. In the lowering direction, tachometer 114 produces an output voltage which is negative at terminal 116 thereby opposing the lowering reference signal. As the speed of the loaded hook 16 increases in the lowering direction, the tachometer 114 output voltage increases. If in lowering, the load tends to overhaul the motor, the tachometer 114 voltage will override the selected speed signal (for speeds less than full speed lowering) thereby saturating the hoist reactors to reverse the phase rotation or sense of the primary excitation to provide sufficient counter torque to keep the load at the command speed.

The limit switch LS may be of any well known type and may include any suitable operator which may be biased by weights or springs to operate the limit switch in its first or normal mode in response to the hook 16 being below a predetermined safe height or upper limit. For example, the limit switch operator may include a beam as shown at 140, pivoted at 142, and biased to the normal operating mode by springs 144 and 146. It should be evident from the drawing that when hook 16 rises above a predetermined safe limit as represented by the normal position of the beam 140, the hook strikes the beam 140 to open contacts LS1 and LS3 and to close contacts LS2. Thus, when the hook 16 is above the limit switch contacts LS2 are closed and contacts LS1 and LS3 are opened. When the hook 16 is below the limit switch contacts LS1 and LS3 are closed and contacts LS2 are opened.

An electromagnetically releasable, spring-set brake 120 is coupled to the motor rotor to brake the motor whenever the release coil 122 of a brake relay BR is not energized. The release coil 122 is connectable to the output of an A.C.-D.C. rectifier 124 when the normally open contacts 126 of a brake relay 128 are closed. The input of rectifier 124 is connected across the resistor 38 to normally receive a portion of the A.C. motor current through contacts LS1 and line L2. The operating coil 128 of brake relay BR is connected across the output of an A.C.-D.C. rectifier 130 having input terminals 131 and 132.

The input of rectifier 130 may be energized from the secondary winding 133 of a transformer 134 through two

possible paths in response to two different conditions. In one case the rectifier 130 and consequently coil 128 are energized in response to the limit switch LS being in its first mode (hook 16 below the LS operator) and the selection of any HOIST or LOWER positions on the controller 68. The circuit for this may be traced from rectifier terminal 131 through normally closed contacts LS3 to the right side of the transformer secondary 133, and from the left side of the transformer secondary through contact fingers 96 and either of segments 104 or 106 (depending on whether the controller is in HOIST or LOWER position) to the rectifier terminal 132. When the hook 16 is above the limit switch operator the brake relay coil 128 can be energized only when the controller 68 is in the 5th point LOWERING position. In this case contacts LS3 are open and the circuit from rectifier 130 may be traced from terminal 132 through controller segment 106 contact fingers 96 to the left side of the transformer winding 133, and from the other side of the transformer secondary through contact fingers 98 and controller segment 108 to the rectifier terminal 131. The primary of transformer 134 may be energized from lines S2 and S3 through a switch 136.

When the hook 16 is below the limit switch LS (LS in first mode) the operating coil 26 of the main contactor M may be energized and latched through the OFF position of the controller 68. The circuit for this condition extends from the lower end of the operating coil 26 through normally closed contacts LS3 to the right end of transformer winding 133 and from the left end of the transformer secondary through contact fingers 94 and controller segment 102 to the upper end of operating coil 26. When operating coil 26 is energized contacts M1, M2, M3 and M4 are closed. Contacts M4 complete a latch circuit to hold main contactor M in.

If the hook 16 rises above the limit switch LS, contacts LS3 are opened, cutting off the current to the operating coil 26 of the main contactor M. With the hook 16 above the limit switch, a circuit to the operating coil 26 may be completed only in response to the controller 68 being in the 5th point LOWERING position and closure of a normally open switch TS which may be a thumb switch located on the controller handle 66. The circuit for this extends from the upper end of operating coil 26 through switch TS, drum segment 106 and contact fingers 96, to the left side of the transformer secondary 133, and from the other side of the transformer secondary through contact fingers 98 and drum segment 108 to the lower end of operating coil 26.

When contacts LS2 are closed, the left end 150 of resistor 38 is connected to line L1, thus connecting motor input terminals T2 to line L1. The opening of contacts LS1 and closure of contacts LS2, in response to the limit switch LS being in its second mode (hook 16 above LS) establishes a single-phase circuit for supplying the motor through lines L1 and L3, line L2 being opened. In this single-phase arrangement, line L3 is connected to motor input terminal T3, while line L1 is connected to motor input terminals T1 and T2 through connections of unequal impedance. It is a known phenomenon that when a running three-phase motor is switched from three-phase supply to single-phase supply, a strong dynamic braking torque is generated, the degree being dependent upon the magnitude of excitation supplied to the motor. Switching the supply voltage to a three-phase motor from three-phase to single-phase is known as "single-phasing" a three-phase motor.

The safety features of the described system operate as follows: Assume that the hook 16 is below the limit switch LS, for example near floor level. Assume further that switch 136 is closed energizing transformer 133 and the controller handle 66 is in the OFF position. Since hook 16 is below the predetermined safe limit, that is below the limit switch LS, the limit switch is in its first or normal mode of operation with contacts LS1 and LS3 closed

and contacts LS2 open. Under these initial conditions, the main contactor M is operated but the brake relay coil 128 is unenergized and brake 120 is set. Controller 68 being in the OFF position, no reference signal is supplied to the hoist and lowering amplifiers by the reference source 64. In order to lift the hook 16 the operator moves the control handle 66 into the HOIST sector. In response to the selection of a HOIST position on the controller 68, contacts 126 are closed to release the brake 120, and the hoist reactors 30 and 36 are saturated to supply excitation to the motor in the proper sense to drive the motor in the hoist direction, thus lifting the hook 16. The magnitude of exciting voltage applied to the motor is dependent on the magnitude of the reference signal supplied by the reference source 64, which in turn is dependent on the particular hoist point which has been selected. First point HOIST produces the lowest lifting speed while fifth point hoist produces the highest lifting speed.

Let it be further assumed that the operator inadvertently misjudges the movement of the rising hook 16 and maintains the controller 68 in the HOIST position until the hook strikes the operator 140 of the limit switch LS. This action opens contacts LS1 and LS3, and closes contacts LS2. The opening of contacts, LS3, opens the circuits to the brake relay operating coil 128 and the operating coil 26 of the main contactor. As a result, and after delays inherent in electromagnetic circuits, contacts 126, M1, M2, M3 and M4 are opened, and brake 120 is set. The opening of contacts LS1 and closing of contacts LS2 establish the single-phase circuit to the motor providing immediate A.C. dynamic braking which takes effect before contacts M1, M2, M3 and 126 open, and therefore before the brake 120 is set. Thus, the motor 20 is braked sequentially by dynamic braking and mechanical braking.

It should be noted that the single-phase dynamic braking circuit is effective in the HOIST position of the controller 68 until the contacts M1, M2 and M3 open. Thus, with the controller 68 in any HOIST position, if a loaded hook 16 rises above the limit switch and for some unknown reason contacts LS3 fail to operate allowing lines L1, L2 and L3 to remain energized and the brake 120 released, the single phase dynamic brake circuit will rapidly brake the drive to a stop, after which the weighted hook will reverse directions and safely descend. Should the controller 68 be left in the HOIST position, the drive would lower until the limit switch LS was passed and then turn around and hoist to operate the limit switch to its second mode again. The drive would continue to recycle as long as the malfunction existed and the controller 68 stayed in the hoist position. This would indicate to the operator that the control was malfunctioning. If the hook 16 rises above the limit switch and contacts LS3 open as they should but contacts LS1 fail to open and contacts LS2 fail to close, the drive will stop and the brake 120 will set.

After the hook 16 has been stopped above the limit switch LS, the hook can be backed out of the limit switch (lowered) in response to the controller 68 only by selecting the highest speed LOWERING position (5th point LOWERING). This position of the controller 68 releases the brake 120 and closes the contacts of the main contactor M. Also in this position of the controller, the potentiometer 82 is in the position to supply the maximum reference signal in the lowering direction. As a result the lowering reactors 32 and 34 are at their lowest impedance and a maximum excitation (average voltage) is applied to the motor through the unbalanced single-phase connection.

If the hook is empty and not heavy enough to lower by itself, the unbalanced single-phase supply to the motor will produce enough torque to start lowering the hook.

This torque results because the line L1 is connected to terminals T1 and T2 through unequal impedances, thus providing sufficient unbalance to produce an out of phase component and cause the motor to rotate. However, as soon as the hook accelerates downward, and this is true with or without load, A.-C. dynamic braking torque is generated in the motor to hold to a safe value the lowering speed. While in fifth point LOWERING, the speed feedback loop is open, so that the lowering reference signal from source 64 is unopposed in the amplifiers 52 and 58, thus maintaining minimum impedance of the lowering reactors and maximum excitation to the motor. This produces high A.-C. dynamic braking.

After the hook 16 lowers past the limit switch LS, all the LS contacts go back to normal, and three-phase excitation is reapplied to the motor. If the controller 68 is maintained at 5th point LOWERING, and the load tries to accelerate beyond synchronous speed, the high excitation to the motor will produce a high degree of regenerative braking, to check the speed of the hook.

The disclosed system requires the operator to go to the 5th point LOWERING and press the thumb switch TS to "back out" of the limit switch. Full voltage is maintained at the motor to assure maximum single-phase voltage to power out with no load and to give maximum A.C. dynamic braking while backing out with load. If the limit switch fails to reset upon backing out, the operator cannot be misled by expecting a slower speed or lesser speed points as the brake sets on any point except the fifth point. Making the operator press the thumb switch TS eliminates the possibility of the operator leaving the master switch in the 5th point LOWERING during a power failure and having the crane energize itself when the control is energized and the limit switch LS is tripped.

The disclosed system provides fail safe circuitry in that if either contacts LS3 or contacts LS1 and LS2 of the power limit switch fail, the drive is still safe.

If this system were to be used in a traveling crane the trolley collectors would lie along the dot-dash line 160. The fail safe features of this system do not require any collectors in addition to those necessary for the basic crane operating system.

It is to be understood that the herein described arrangements are simply illustrative of the principles of the invention, and that other embodiments and applications are within the spirit and scope of the invention.

We claim as our invention:

In a reversible load lifting system including load lifting means driven by a three-phase motor having first, second and third input terminals, a supply circuit connected to the motor terminals for supplying power to the motor, said supply circuit having first switch means operable in open and closed modes for opening and closing the power circuit to the motor, said supply circuit further including first, second and third phase lines connected to said first second and third terminals respectively, a releasable brake which is normally biased set for braking said lifting means, limit means which assumes first and second modes in response to said load lifting means being respectively below and above a predetermined limit, a control circuit including master controller means and current control elements in said supply circuit responsive to the master controller means for controlling the direction and speed of the motor, said controller means having selectable hoists and low and high speed lowering positions, means including said limit means in its first mode for establishing a first switch operating circuit for operating said first switch means to its closed mode, means including said controller means in its high speed lowering position only for establishing a second switch operating circuit for operating said first switch means to its closed mode, means including said limit means in its first mode and said controller means in any of said hoist or lowering positions for establishing a

first brake release circuit for releasing said brake, means including said controller means in the high speed lowering position only for establishing a second brake release circuit for releasing said brake, means including said limit means in its second mode, said controller means in either said hoist or high speed lowering positions only, and said first switch means in its closed mode, for providing an unbalanced single phase energizing circuit to the motor wherein one of said phase lines is open-circuited relative to its associated motor input terminal, said energizing circuit including connections of unequal impedance from another of said phase lines to said associated terminal and another of the motor terminals, and a connection from the remaining phase line to the remaining motor terminal.

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