April 26, 1949. Z. W. WHITEHOUSE 2,468,609

MOTOR CONTROL

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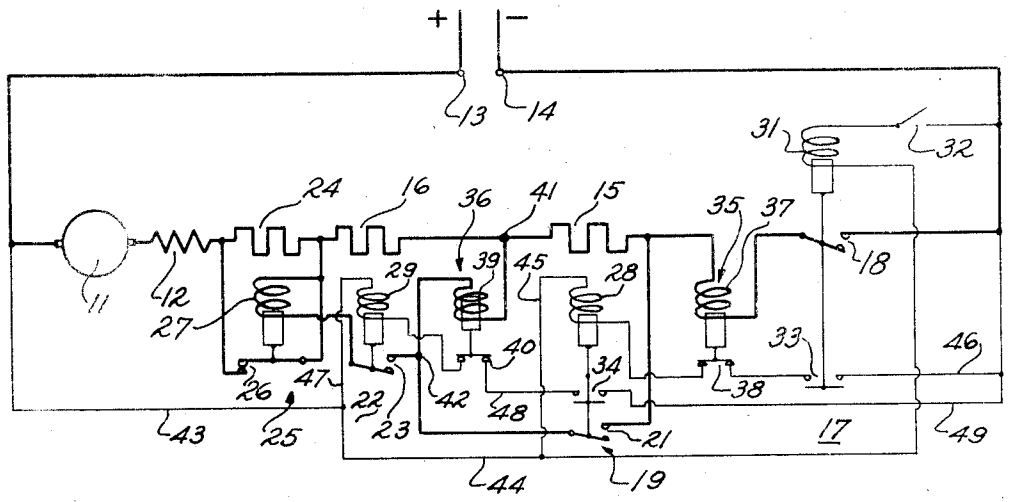


Fig. 1

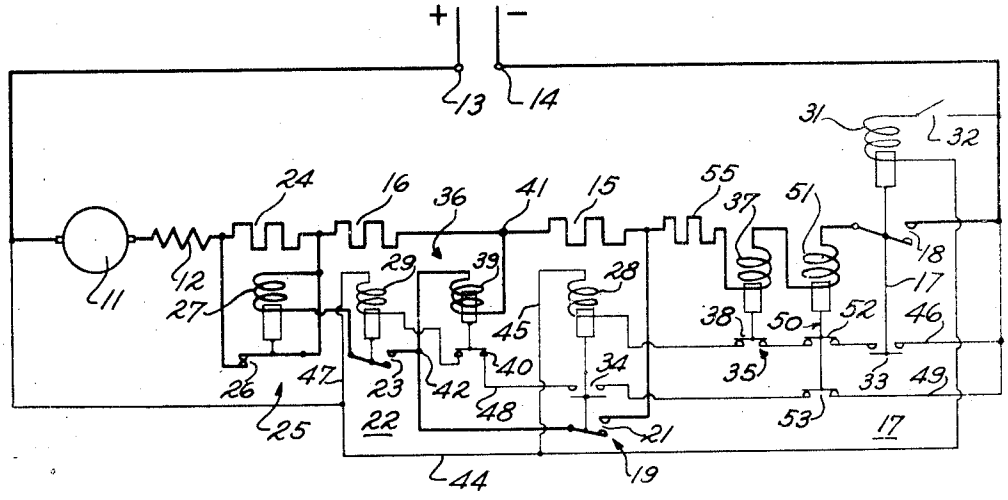


Fig. 2

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MOTOR CONTROL

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My invention relates to control systems and concerns particularly control systems for motors which may be operated under such conditions as to be subjected to the possibility of jamming or stalling.

An object of my invention is to protect electric motors whether of the series, shunt, or compound type from burning out or from over-heating in the event of being stalled or jammed or subjected to excessive torque load, especially after the starting resistors have been cut out.

Another object of my invention is to limit the jamming current or stalling current in a motor to a predetermined peak value independent of values of accelerating peaks which may be employed in accelerating the motor or bringing it up to speed when it is initially being started, or placed on the line.

Another object of the invention is to provide jam current protection which is quick-operating.

A further object is to provide for motor protection in which accelerating peaks may be permitted to continue for predetermined lengths of time when the motor is being placed on the line, but jam current protection is provided substantially instantaneously in case jamming current or stalling current rises to a predetermined value after the motor has been started, in the event the motor should be subjected to excessive torque load or should be stalled.

Still another object of my invention is to provide jam current protection at current values independent of accelerating current peaks employed in placing the motor on the line, and to provide jam current protection at a current value substantially smaller than the accelerating peaks permitted when the motor is first started or placed on the line.

Another object is to provide jam current protection responsive to a given current value while acceleration resistance is connected in series with the motor and exceedingly rapid acting jam current protection responsive to a different current value after all of the acceleration resistance has been excluded.

Other and further objects, features and advantages will become apparent as the description proceeds.

In carrying out my invention in its preferred form, I provide a conventional starting system having a starting resistance with a plurality of sections in series with each other and with the motor armature, or what amounts to the same thing—a plurality of starting resistors in series, with accelerating contactors connected in respective loop circuits for successively cutting out or shunting the starting resistance sections or the separate starting resistors. In addition I provide a separate jam current limiting resistor (or resistance section) in series with the starting resistance means and having an independent jam current contactor which is normally closed for cutting out the jam current resistance. The jam contactor has an actuating winding connected in the loop circuit of and in series with one of the accelerating contactors, preferably the last accelerating contactor to close when the motor is started or placed on the line.

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A better understanding of the invention will be afforded by the following detailed description considered in conjunction with the accompanying drawing, and the scope of the invention will be set forth in the accompanying claims.

In the drawing:

Fig. 1 is a circuit diagram of an illustrative embodiment of my invention, and

Fig. 2 is a circuit diagram of a modification.

Although my invention may be employed to advantage, in motor starting systems having any number of steps of increase of current or of cutting out starting resistors, for the sake of simplicity in the drawing and description, I have shown an embodiment of the invention in which only two steps of starting resistors are employed for bringing the motor up to speed and connecting it directly across the line. The invention may be employed in connection with A.-C. or D.-C., series, shunt, or compound wound motors with or without reversing connections, but for the sake of illustration the invention will be described in connection with a series wound direct-current motor.

As shown in Fig. 1 of the drawing, there is a motor having an armature 11 in series with a series field winding 12. Current supply terminals 13 and 14 are provided which, in the arrangement illustrated, are represented as being the positive and negative terminals respectively of a direct-current supply source.

A conventional motor starter is provided which is preferably an automatic starter including steps of starting impedance, which may take the form of sections of resistance 15 and 16 in series with the motor 11—12 and the current supply terminals 13 and 14.

Preferably, a starting contactor 17 is provided having a pair of normally-open main-line contacts 18 in series with the starting resistor sections 15 and 16, and the motor armature 11 in the main line to the supply terminals 13 and 14.

A plurality of accelerating contactors are also provided, one for each of the starting resistor sections. In the specific arrangement described with two starter resistor sections, there is an accelerating contactor 19 having a pair of normally open main line contacts 21 adapted to shunt the initial step of starting resistance or the initial starting resistor section 15, and there is a final accelerating contactor 22 having a pair of normally open main line contacts 23 adapted to shunt out the final step of starting resistance or the final resistor section 16. As will be explained more in detail hereinafter, means are provided for causing the starting contactors 17, 19 and 22 to operate successively closing the contacts 18, 21 and 23. The specific means utilized for causing the contacts to operate in succession do not however constitute a part of my present invention.

In order to prevent the motor 11 from over heating or burning out in the event that excessive torque load should be applied thereto or it should be stalled or jammed after it has been brought up to speed, or after the contacts 18, 21 and 23 have been closed, means are provided for inserting current-limiting resistance in series with the armature 11. Preferably a separate, independent jam resistor 24 is provided which is connected in series with the armature 11 and the main line. For preventing the jam resistor 24 from being effective except when needed, a jam contactor 25 is provided having a pair of normally closed contacts 26 connected across the jam resistor 24. Means are provided for causing the jam contactor 25 to operate automatically, whenever the current through the armature 11 exceeds a predetermined value after the contactor 22 has closed. Preferably the arrangement is such that the jam resistor 24 may be introduced in the circuit upon the occurrence of a jam current of a lower peak value than the accelerating peaks permitted upon closure of the accelerating contactors before the last, in this case, lower than the accelerating peaks which occur upon closure of the contactors 17 and 19. To this end the jam contactor 25 has an actuating winding 27 preferably not connected directly in series with the main line to the supply terminals 13 and 14, but in series with one of the accelerating contactors. Preferably, as illustrated, the jam contactor actuating winding 27 is connected in series with the last accelerating contactor 23 so that the jam resistor 24 and the jam contactor 25 can not come into operation until all of the accelerating contactors have been closed and the motor 11 has been placed directly across the line.

In the specific arrangement illustrated for causing the accelerating contactors 19 and 22 to operate in succession in response to reduction of accelerating current to predetermined values, shunt windings actuated by a separate control circuit are provided. The first accelerating contactor 19 is provided with a shunt winding 28 and the accelerating contactor 22 is provided with a shunt winding 29. The main contactor 17 is provided with an actuating winding 31 adapted to be energized from the supply terminals 13 and 14 through a starting switch 32. As shown, the main contactor 17 is provided with normally open auxiliary contacts 33 for preventing the energization of the contactor 19 until the contactor 17 has been closed; likewise the first accelerating contactor 19 is provided with normally open auxiliary contacts 34 for preventing the second auxiliary contactor 29 from being actuated until after the contactor 19 has operated.

An acceleration relay 35 is provided for preventing the contactor 19 from operating for a time interval after the contactor 17 closes, and a similar acceleration relay 36 is provided for preventing the contactor 22 from operating for a time interval after the contactor 19 closes. The relays 35 and 36 are preferably arranged to give time-current acceleration, holding their contacts open for a time interval which is greater with greater values of current. The relays 35 and 36 may be of any suitable type but preferably are similar to the acceleration relay disclosed in Patent No. 1,980,736 issued to Lev A. Trofimov on November 13, 1934. The relay 35 comprises a series winding 37 interposed in the line leading to the terminal 14, and normally closed contacts 38 connected in the control line in series with the actuating winding 28 of the first acceleration contactor 19. The relay 36 has a series winding 39 and normally closed contacts 40. The winding 39 is connected between a junction terminal 41 of the starting resistor sections 15 and 16 and a junction terminal 42 between the pairs of accelerating contacts 21 and 23; and the contacts 40 are in series with the actuating winding 29 of the accelerating contactor 22.

In the arrangement illustrated in Fig. 1, when the motor 11 is to be started, the switch 32 is closed energizing the winding 31 of the contactor 17 thereby to close both the main contacts 18 and the control contacts 33. Closure of the contacts 18 completes a circuit from the terminal 13, through the armature 11, the field winding 12, the normally closed contacts 26, the starting resistor sections 16 and 15, the winding 37, and the contacts 18 to the supply terminal 14. Closure of the control contacts 33 completes a circuit from the terminal 13 through the conductors 43, 44 and 45, the winding 28 of the first accelerating contactor 19, the normally closed contacts 38, the now closed contacts 33, and the conductor 46 to the supply terminal 14. Before the contactor 19 can operate in response to completion of the above described circuit through its operating winding 28, the normally closed contacts 38 of the relay 35 open in response to energization of the winding 37 by the rise of acceleration current flowing to the motor. After a time interval dependent upon the magnitude of the motor current during the time interval and as described in the above mentioned Trofimov patent, the contacts 38 reclose to complete the circuit for the winding 28 thereby to cause operation of the contactor 19 and closure of the contacts 21 and 34 thereof. Closure of the contacts 19 completes a short circuit around the resistor section 15 causing an increase in the voltage applied to the armature 11. The sudden rise in current through the short-circuiting loop including the contacts 19 and the winding 39 of the relay 36 causes opening of the contacts 40. The contacts 40 remain open for a time interval dependent upon the magnitude of the motor current flowing during the interval and then reclose to complete an operating circuit for the winding 29 of the last accelerating contactor 22. The circuit for the winding 29 is from the terminal 13 through the conductor 43, the winding 29, the now closed contacts 40 and 34, and the conductor 46 to the terminal 14.

Closure of the contacts 22 completes a short circuit around the resistor section 15 through the winding 27 of the jam conductor 25. The motor is now connected directly across the terminals 13 and 14 without series resistance effectively in the circuit. The foregoing sequence of acceleration switch operating takes place whether the motor

rotates or not and is timed in proportion to the magnitude of the motor current, a longer time being required to complete the sequence if the motor is heavily loaded than if it is lightly loaded.

Owing to the fact that accelerating current peaks are usually of relatively short duration while the motor is being brought up to speed, and owing to the fact that in order to bring the motor up to speed with the desired rapidity the accelerating or starting current must reach values of several times the normal running current value, the resistance values of the several starting resistance sections are so selected and the timing relays so adjusted that the acceleration current reaches values considerably in excess of the amount which could safely be allowed to pass through the motor during normal running. Accordingly, when the motor is operated under such conditions that, after being energized, it may become jammed or stalled, it is desirable to provide jamming protection responsive at a lower value of motor current than the peak values occurring during acceleration. In the arrangement illustrated in Fig. 1, it will be observed that the jamming contactor **25** cannot be energized and does not have its operating winding **27** connected in the motor circuit until after all of the accelerating contactors have operated. Accordingly, the acceleration current peak that occurs upon initial connection of the motor to the source and the current peaks that occur upon closure of the acceleration contactors preceding the last accelerating contactor may be in excess of the pick-up current value of the contactor **25**. Since the operating winding **27** of the jamming contactor is disconnected until the last acceleration contactor closes, the pick-up current value of the jamming contactor **25** may be reduced below the acceleration current peaks thereby rendering the protective means faster operating and preventing false and premature operation of the jamming contactor **25** thereby not to interfere with fast motor starting.

After all the accelerating contacts, including the last accelerating contact **23**, have closed and the motor is directly connected to the line, the jamming contactor **25** is in condition to operate and if the motor current should exceed the value at which it will be safe to permit current to flow with the armature **11** jammed or stalled, the contacts **26** open so as to introduce the jam resistor **24** and limit the current flow to the safe value. Inasmuch as the jam resistor **24** is introduced into the circuit only after the motor has been connected across the line, its value may be chosen independently of the value of the resistances of the starting resistors **15** and **16**, and may be different from the total starting resistance or the resistance of any one of the starting resistors or resistor sections or any combination of such sections. Consequently, the jam or stalling current to which the current flow is limited when the motor is jammed or stalled or encounters excessive torque load, may be selected independently of the values of resistance utilized in the starting resistor and independently of the values of current controlled by the accelerating contactors and starting relays. In consequence the optimum value of motor acceleration current may be chosen and the optimum value of maximum permitted stalling or jamming current may be chosen independently of each other.

A further advantage in having a separate jam resistor **24** is that its ohmic value may be selected so as to prevent pumping, i. e. repeated opening and closing, of the jam contactor **25**. A magnetic contactor such as the contactor **25** normally has a pick-up current value approximately equal to three times its drop-out value. If the series resistance introduced into the circuit as a result of opening of the jam contactor is excessive, the current flowing to the motor decreases to a value below the drop-out value of the jam contactor, which thereupon recloses its contacts to again short circuit the jam resistor. The motor current then increases and the jam contactor picks up again. This cycle would be repeated until the jam condition is removed or the overload protective means (not shown) for the motor responds. By use of the separate resistor **24**, this pumping action is prevented merely by selecting the proper resistance value.

The jam contactor **25** is preferably designed to be extremely rapid in operation. For example, many of the moving parts may be made of light alloys and the distance of armature travel is preferably made as small as possible. The speed of operation of the contactor **25** under jam conditions may be further increased by having the pick-up current value of the contactor below the peak values of the acceleration current. Heretofore, reduction in the pick-up current value of jam protection means even to values but slightly above the acceleration current peaks has not been successfully obtained except by the use of a series of relay controlling a separate contactor or contactors with the inherent delay present in such an arrangement. By use of a series wound contactor connected as above described, the response to a jam condition is substantially instantaneous. The jam current causing operation of the contactor can be below the acceleration peaks and the use of a separate jam resistor makes it a simple matter to prevent pumping.

For the sake of simplicity only three steps of acceleration (two steps of starting resistance) and a single step of jamming current limitation have been shown in Fig. 1 of the drawing, but it will be understood that the invention is not limited to utilizing only a single section jam current limiting resistor **24** and utilizing only a single jamming current contactor set for a single value of current.

Although my invention is not limited thereto, the arrangement for cutting in the jam current limiting resistor **24** is preferably a series winding carrying the motor current, such as the actuating winding **27** in series with the last accelerating contacts **23** in order to insure positive action and opening of the contacts **26** whenever the jam current exceeds the desired value. In this manner, the operation of the jam contactor is not dependent upon continuity of a control circuit or upon the absence of sticking of a separate operating relay, for example.

In the modification of Fig. 2 a jam switch **50** which may be either a relay or contactor is added to the system of Fig. 1 and has an operating winding **51** interposed in the line leading to the terminal **14** and normally closed contacts **52** and **53** interposed in the conductors **46** and **49**, respectively. The jam switch **50** preferably has a relatively large air gap in its magnetic circuit so that its pick-up and drop-out current values are as close together as possible. The arrangement of Fig. 2 is especially suitable for applications wherein jam conditions frequently occur before the motor gets up to speed or before all of the acceleration contactors are closed. Thus a jam condition occuring at any time causes opening of the contacts **52** and **43** and prevention of the contactors **19** and **22** from closing or droping out those contactors if they have already closed. Opening

of the contactor 19 and 22 reinserts all of the acceleration resistance into the motor circuit to protect the motor. The pick-up and drop-out current values of the switch 50 are so selected that pumping does not occur. A resistor 55 of relatively low ohmic value may be permanently connected in series with the motor if desired to prevent excessive current surges in event the motor comes to a sudden stop before the last acceleration contactor 22 closes. If a jam condition occurs after the contactor 22 has closed, the jam contactor 25 responds to insert the jam resistor 24 into the circuit before the current can rise to a dangerous value and before operation of the switch 50 can cause drop-out of the contactors 19 and 22. In certain applications, as for example the side guard drive of a rolling mill, it may be desired to have the pick-up value of the contactor 25 equal to or above that of the switch 50 so that the guard may be kept moving when it strikes an ingot that can be moved, the sudden but temporary rise in current due to the sudden application of such a high inertia load not causing operation of either the contactor 25 or the switch 50.

While I have described a particular embodiment of my invention and certain apparatus for carrying out my method, it will be obvious to those skilled in the art that various modifications may be made without departing from the spirit of my invention, and I therefore desire to cover all such modifications as fall within the scope of my invention which is set forth in the appended claims.

What is claimed is:

1. In a motor starting system in combination a motor armature, current supply terminals, a jam resistor, a plurality of accelerating resistors connected in series with said current supply terminals and said motor armature, a plurality of accelerating contactors connected in loop circuits with said accelerating resistors respectively, means for closing said contactors in succession, a normally closed jam contactor connected across said jam resistor, and an actuating coil for said jam contactor connected in series with and in the loop circuit of the accelerating contactor which closes last in succession.

2. In a motor control system the combination of current supply terminals, an electric motor, a jam resistor, and a plurality of accelerating resistors, all connected in series, normally open accelerating contactors connected in loop circuits with said accelerating resistors respectively, a normally closed jam contactor connected across said jam resistor, and an actuating coil for said normally closed jam contactor connected in series with and in the loop circuit of one of said accelerating contactors.

3. In combination with a motor having accelerating resistors and normally open accelerating contactors in loop circuits with said resistors, respectively, adapted to close successively, a jam resistor connected in series with said motor, a normally closed jam contactor connected across said jam resistor, and an actuating coil for said jam contactor connected in series with and in the loop circuit of one of said accelerating contactors.

4. In a control system for an electric motor, means for controlling the magnitude of the motor starting current including resistance having accelerating contacts in loop circuits with portions thereof, a jam current reducing resistor for connection in series with the motor, normally closed contacts connected across said jam resistor, and an actuating coil for said normally closed contacts connected in series with and in the loop circuit of one of said accelerating contacts.

5. In combination an electric motor, a jam current reducing resistor, a plurality of accelerating resistors, and current supply terminals to which said elements are connected in series, accelerating contactors connected in loop circuit with said accelerating resistors respectively, said contactors being adapted to close in succession for accelerating the motor, normally closed jam contacts across the jam current reducing resistor, and an actuating coil for said jam contacts connected in series with and in the loop circuit of one of said accelerating contactors, said jam current reducing resistor having a different resistance value from the total resistance of said accelerating resistors.

6. In combination an electric motor, a jam current reducing resistor, a plurality of accelerating resistors, and current supply terminals to which said elements are connected in series, accelerating contactors connected in loop circuits with said accelerating resistors respectively, said contactors being adapted to close in succession for accelerating the motor, normally closed jam contacts across the jam current reducing resistor, and an actuating coil for said jam contacts connected in series with and in the loop circuit of one of said accelerating contactors, said jam current reducing resistor having a different resistance value from any of said accelerating resistors.

7. The method of operating an electric motor which comprises starting the motor by successive increments of applied voltage, controlling the time intervals between successive increments in accordance with the magnitude of accelerating current and, after the next to the last increment has taken place, reducing the current substantially instantaneously whenever the current exceeds a predetermined value.

8. In combination, an electric motor, accelerating resistors in series therewith, contactors for cutting out said resistors, slow acting means for introducing said resistors in the event of accelerating current peaks exceeding predetermined values, a jam current resistor in series with said motor and a jam contactor of the fast acting type for introducing said jam current resistor in the event of flow of current exceeding a predetermined value.

9. In combination, a motor starter comprising means operable in time-delayed sequence for controlling the starting current of a motor, a jam current reducing resistor arranged to be connected in series with the motor, fast acting jam current control means having normally closed contacts connected across said jam resistor, and means for causing substantially instantaneous opening of said contacts upon occurence of a jam condition of said motor after operation of said first named means.

10. In combination, an electric motor, a plurality of starting resistors connected in series therewith, accelerating contactors operable in time delayed sequence connected in loop circuits with said resistors respectively, a jam current reducing resistor connected in series with said motor, fast acting jam-current control means having normally closed contacts connected across said jam resistor and an actuating coil for causing substantially instantaneous opening of said jam contacts, said coil being connected in series with and in the loop circuit of one of said accelerating contactors.

11. The method of operating an electric motor which comprises starting the motor by successive increments of applied voltage, and, after a predetermined number of increments of applied voltage have taken place, reducing the current sub-

stantially instantaneously whenever the current exceeds a predetermined value.

12. A motor control system comprising in combination series impedance for limiting starting current, contactor means connected across said impedance, means for operating the contactor means to accelerate a motor, a series jam current limiting resistor means responsive to a flow of current above a predetermined value for inserting said jam current resistor after the said contactor means have operated, and second jam current control means for reducing motor current independently of the operation of said accelerating contactor means.

13. In combination, an electric motor, a plurality of starting resistors connected in series therewith, accelerating contactors connected across said resistors, a jam current reducing resistor connected in series with said motor, normally closed jam contacts connected across said jam resistor having an actuating coil connected in series with one of said accelerating contactors for causing insertion of said jam resistor in series with the motor in response to current exceeding a predetermined value after the said last mentioned accelerating contactor has closed, and a second jam contactor having an actuating winding in series with said motor for insuring open condition of said accelerating contactors in response to motor current exceeding a predetermined value either before or after closing of the accelerating contactors.

14. In combination, an electric motor, a plurality of starting resistors connected in series therewith, accelerating contactors connected across said resistors, a jam current reducing resistor connected in series with said motor, a normally closed jam contactor connected across said jam resistor having an actuating coil connected in series with one of said accelerating contactors for causing insertion of said jam resistor in series with the motor in response to current exceeding a predetermined value after the said last mentioned accelerating contactor has closed, and a second jam contactor having an actuating winding in series with said motor for causing open condition of said accelerating contactors in response to motor current exceeding a predetermined value either before or after closing of the accelerating contactor, said first jam contactor having a higher pick-up value than the second jam contactor.

15. In combination, an electric motor, a plurality of starting resistors connected in series therewith, accelerating contactors connected across said resistors, a jam current reducing resistor connected in series with said motor, normally closed jam contacts connected across said jam resistor having an actuating coil connected in series with one of said accelerating contactors for causing insertion of said jam resistor in series with the motor in response to current exceeding a predetermined value after the said last mentioned accelerating contactor has closed, and a second jam contactor having an actuating winding in series with said motor for causing open condition of said accelerating contactors in response to motor current exceeding a predetermined value either before or after closing of the accelerating contactors, said second jam contactor having a magnetic circuit with a relatively large air gap therein so as to cause the pick-up and drop-out current values of the contactor to be relatively close together.

16. The method of operating an electric motor which comprises starting the motor by successive increments of applied voltage, controlling the time intervals between successive increments in accordance with the magnitude of accelerating current, reducing the current whenever the accelerating current exceeds a predetermined value, and after the next to the last increment has taken place, reducing the current substantially instantaneously whenever the current exceeds a predetermined value.

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