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(54) ELECTRIC MOTOR CONTROLLING SYSTEM

(71) We, HITACHI LTD., a Corporation organised under the laws of Japan, of 5-1, 1-chome, Marunouchi, Chiyoda-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 The present invention relates to an electric motor controlling system, and more particularly, to a system for controlling both the motoring torque and the braking torque of an electric motor system consisting of at least one electric motor.

15 Induction motors are used in many fields of industry because of their general utility. In particular, they have been widely used in the fields which do not require precise speed control. Recently, with the advent of the thyristor, considerably more precise speed control of the induction motor has become possible.

20 For example, in elevator systems, elevators of the popular type have employed the induction motor, while high class elevator systems have employed the DC motor capable of easily performing precise speed control. However, if speed control of the induction motor is performed by the use of the thyristor, considerably more precise control can be ensured, and hence its application field is widening.

25 There are various modes of controlling the motoring torque of the induction motor by the use of the thyristor, among which one called "primary voltage control" in which the voltage supplied from the AC source to the induction motor is controlled, is most prevailing.

30 With primary voltage control the following two methods are conceivable:

35 (1) The method in which the thyristor is connected between the AC source and the induction motor; and

40 (2) The method in which the AC source is connected to the primary winding of the induction motor and the thyristors are con-

50 nected between the end terminals of individual phases of the primary winding.

Each of the above methods has various possible modifications. For example, the first method (1) has the variants

55 (a) The anti-parallel circuit of a thyristor and a unidirectional element, and

60 (b) The anti-parallel circuit of a pair of thyristors. These anti-parallel circuits are used in the three-phase control in which the anti-parallel circuit is connected to all the three phases, the two-phase control, or one-phase control.

Of course, there are also many other possible variants.

65 On the other hand, as methods of controlling the braking torque of the induction motor using thyristors,

(i) The DC braking; and

70 (ii) The regenerative braking systems are typical. When the braking torque is necessary right down to a low speed region, the regenerative braking system is unsuitable, but DC braking is desirable.

75 In a field in which the control of both motoring torque and braking torque are necessary such as the elevator, both motoring torque control systems and braking torque control systems are provided. These control systems are commonly changed over to each other between periods of motoring and periods of braking, and controlled depending on the difference between the set speed and the actual speed (hereinafter referred to as the speed deviation). That is, when the elevator is accelerating the primary voltage of the induction motor is controlled in accordance with the speed deviation, so that the speed of the elevator increases following the set speed. When the elevator is to decelerate, the DC braking current is controlled in accordance with the speed deviation, so that the elevator is decelerated following the set speed against its inertia.

95 This system has the following disadvantages:

(1) Since the speed control at the deceleration time relies only on the control of the braking torque, the inertia of the elevator including the motor must be large because, if the inertia is small, the elevator may stop before it reaches the set floor. To ensure that the elevator reaches the set floor, it is necessary to increase the moment of inertia of the motor. For this purpose, an inertial body may be mounted on the motor shaft, or the moment of inertia of the motor itself may be made large. As a result, a large motoring torque becomes necessary at the accelerating time, and it is necessary to absorb the accumulated inertial energy at the deceleration time by heat dissipation due to the DC braking. Consequently, the size of the motor becomes large from the consideration of the moment of inertia and the heat dissipation, while the capacity of the motor becomes large from the necessity of a large torque.

(2) The control gain of each of the control of the motoring torque by the primary voltage control and the control of the braking torque by the DC braking is low and the performance thereof is bad in the state that the control deviation, for example the speed deviation is small. Consequently, even if the speed instruction becomes zero, the elevator cannot easily stop. For this reason, it is necessary to mechanically lock the elevator by an electromagnetic brake in the state that the elevator has a certain degree of speed to stop it. As a result, the elevator becomes uncomfortable to ride in. The uncomfortableness of the elevator to ride in also occurs at the switching point from motoring to braking.

An electric motor controlling system according to the invention comprises an electric motor apparatus including a first motor portion and a second motor portion, each of the portions consisting of a motor or a motor winding, a first control unit for controlling a motoring torque generated by said first motor portion, a second control unit for controlling a braking torque generated by said second motor portion, means for generating a speed instruction signal, first control means for controlling said first control unit in accordance with the value of a difference between said speed instruction signal and a signal representative of an actual speed of said motor apparatus when said difference is positive, second control means for controlling said second control unit in accordance with the value of said difference when said difference is negative, and means for biasing at least one of said first and second control means so that the motoring torque and the braking torque are simultaneously generated in the region of a small value of said difference.

The present invention may thus provide an

electric motor controlling system enabling a set speed to be maintained throughout its operation from motoring to braking even when the moment of inertia of the motor shaft is small.

The present invention may also provide an electric motor control-lines system having a high control gain and good control performance even in the region of a low control input.

The expression "push-pull" characteristic is used herein to mean a combined output characteristic having a continuous high gain over a region of a control input from positive to negative value, produced by a first means for generating a positive going output corresponding to the value of the control input when the control input is positive and by a second means for generating a negative going output corresponding to the value of the control input when the control input is negative such that, when the control input is in a region near zero, their outputs are in opposite directions to each other.

By using the system of the invention, the torque obtained from the motor apparatus can be controlled as desired and the control performance becomes good even in a region of the control input near zero under any conditions.

A further feature of the present invention is the provision of means for detecting an electrical quantity relating to the produced torque of at least one of said first and second motor portions and means for negatively feeding back an output of said detecting means to the control means associated with the other motor portion.

By the above feature, the control gain at a region of the control input around zero can be further increased.

A further feature of the present invention is that the motor apparatus comprises first and second induction motors, and the torque control means of these induction motors include thyristors so that a completely continuous torque control of the motor apparatus can be made in a contactless manner over a wide range from motoring to braking.

The above and other objects, features, and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiment of the present invention made by way of example only when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a schematic circuit diagram of an embodiment of the electric motor control-lines system according to the present invention as applied to an elevator driving system;

Fig. 2 is a block diagram of the system of Fig. 1;

Figs. 3 and 4 are speed deviation versus

motor torque characteristics for explaining the present invention; and

Fig. 5 is speed, current, and acceleration waveform relative to time for explaining the operation of the elevator.

Referring to Fig. 1, an elevator car CA and a counter weight CW are suspended from a traction sheave TS by a rope RP. The traction sheave TS is coupled to induction motors HM and LM through a reduction gear RG, a tachometer generator TG, and an electromagnetic brake MB.

The high speed induction motor HM and the low speed induction motor LM are directly coupled. However, a pair of induction motors are not always necessary, but instead a pair of windings serving respectively as the motoring torque generating means and the braking torque generating means may be provided in one induction motor. Commonly, the latter will be prevailing.

To a three phase AC source U, V, W contacts 111 and 112 which close when the elevator runs up and contacts 121 and 122 which close when the elevator runs down are connected through a main contact MC. Further, contacts 131 and 132 which close at the time of ordinary running are connected in the source circuit. Between these contacts and the high speed induction motor HM a primary voltage controller WR is connected. The primary voltage controller WR consists of an anti-parallel circuit of thyristors. Fig. 1 shows an example of the two phase control.

A low speed run of the elevator at a maintenance and inspection time is indispensable in addition to ordinary service run for passenger. For this reason, it has been common for the elevator utilizing an induction motor as its driving source to be equipped with a high speed induction motor HM with a small number of poles to be used at motoring and high speed operation time and a low speed induction motor LM with a larger number of poles. The low speed induction motor LM was also partly used for braking at deceleration time.

In the present invention, it is unnecessary to especially employ a low speed induction motor LM. However, when the present invention is applied to the existing elevator facilities, there is the advantage that the low speed induction motor LM can be utilized as it stands, and particularly at the DC braking, a large braking torque can be provided because of the large number of poles of the induction motor LM.

Contactors 141 and 142 inserted between the AC source and the low speed induction motor LM are closed at the time of the maintenance and inspection running.

A DC braking circuit consisting of a transformer TR, a controllable rectifying

circuit VR, and contactors 133 and 134 to be closed at the service running is connected between two terminals of the three phase AC source and two terminals of the low speed induction motor LM.

The controllable rectifying circuit VR is a bridge rectifying circuit consisting of a pair of thyristors TH1 and TH2 connected in series on opposite sides of one AC side terminal a1 and a pair of unidirectional elements such as silicon rectifying elements SR1 and SR2 connected in series on opposite sides of the other AC side terminal a2. According to the above construction, when the AC voltage applied between the AC terminals a1 and a2 is low, there is the advantage that the fly-wheel effect occurs and the fluctuation of the DC braking torque is reduced because the electromagnetic energy produced in the low speed induction motor LM can flow through the unidirectional elements SR1 and SR2.

The above description is as to the main circuit. A description of the control system will next be made with reference to Figs. 1 and 2.

A pattern generator PG consists of an acceleration pattern generator APG which provides an output increasing with the time, a deceleration pattern generator DPG which provides an output decreasing with the position of the elevator, and a lower priority circuit LPC which provides preferentially a lower one of the outputs of the acceleration and deceleration pattern generators APG and DPG as a speed instruction SP as shown in Fig. 2. The deceleration pattern generator DPG is provided with a detection board 91A to 91E and 91 arranged in the elevator passage and a position detector P arranged on the elevator car, the position detector P producing at the deceleration time a stepwise decreasing output by detecting the detection board sequentially as shown in Fig. 1.

The output of the pattern generator PG is applied to three comparators CP1, CP2, and CP3 as their one input, and the other input is supplied as a speed feedback by the tachometer generator TG. The outputs of these comparators CP1, CP2, and CP3 are supplied to phase shifters PS1, PS2, and PS3 and phase control the thyristors in the primary voltage controller WR and the controllable rectifying circuit VR. These elements construct a speed control system.

Consequently, the motoring torque and the braking torque are controlled in accordance with the speed deviation S. The speed deviation S versus torque τ_M characteristic for the motoring torque and the braking torque is shown in Fig. 3 as curves τ_{HM} and τ_{LM} , respectively. The high speed induction motor HM produces the positive torque (motoring torque) only during the posi-

tive period of the speed deviation S , while the low speed induction motor LM produces the negative torque (braking torque) only during the negative period of the speed deviation S .

Considering the positive and negative regions of the speed deviation S , the torque curves τ_{HM} and τ_{LM} are connected with each other to provide a continuous torque curve from motoring to braking. Consequently, even when the elevator cannot reach the set point by controlling only the braking torque because of a small inertial energy at the deceleration time of the elevator, the speed can be controlled to the set point accurately following the speed instruction, since the high speed induction motor HM can produce the motoring torque τ_{HM} due to the fact that the speed deviation S is positive. Thus, it is unnecessary to increase the moment of inertia of the motor shaft, and the necessity to increase the capacity of the motor and heat loss can be avoided.

However, as is apparent from Fig. 3, the variation in the torque is small in a region of the speed deviation S around zero. Consequently, the response to the variation in the speed instruction is slow. In particular, even if the speed instruction becomes zero immediately before the stoppage of the elevator, the speed deviation S is small, so that the elevator would not readily stop as described above.

Accordingly, the present invention gives the push-pull characteristic to the torques of the motoring torque control system and the braking torque control system for the control input. By applying biases $B1$ and $B2$ to the comparators $CP1$ and $CP2$, $CP3$, respectively, the speed deviation S is biased on the coordinate system of Fig. 3. As a result, the axis of ordinates $S=0$ is shifted as indicated by dotted lines by the amounts of bias $SB1$ and $SB2$. Thus, when the amount of the speed feedback is SF , for example, for the speed instruction SP ($SP < SF$), the braking torque control system produces the braking torque at a point b_1 , and the motoring torque control system produces the motoring torque at a point m_1 . If these are written on the same coordinate system, both motoring torque τ_{HM} and braking torque τ_{LM} are produced in a region of the speed deviation S around zero, and the combined torque of the directly coupled induction motors HM and LM becomes a torque curve having a high gain even in the region of the speed deviation S as shown by a dotted line in Fig. 4. The combined torque for the speed instruction SP and the speed feedback amount SF is at a point b_2 , the braking torque.

Consequently the speed response of the elevator to the speed instruction is quick, and when the speed instruction becomes zero, the

elevator can be quickly stopped. As a result, it becomes unnecessary to apply the electromagnetic brake MB in the state of a relatively high speed immediately before the stoppage of the elevator, so that the vibration of the elevator car CA is prevented and comfort of the ride is improved.

The biases $B1$ and $B2$ are not always necessary to be applied to both control systems, nor to be of the same value when applied to both control systems. In setting these values, offset errors or the like are to be taken into consideration. Also, it is possible to eliminate the biases by selecting the characteristics of the phase shifters.

In order to further improve the control gain, it is desirable to negatively feed an electrical quantity relating to the motoring or braking torque back to the other torque control system. In the embodiment described, a current detector CD for detecting the braking current which is proportional to torque is provided, and the output thereof is negatively fed back to the comparators $CP1$ and $CP2$.

By constructing as above, when the braking torque τ_{LM} is produced, it functions to decrease the motoring torque τ_{HM} . In Fig. 4, when the speed deviation S comes to the region at which the braking torque is produced while it is gradually decreasing from a sufficiently large positive region, the motoring torque τ_{HM} is depressed to a value less than the characteristic represented by the solid line, so that the slope, i.e. gain of the combined torque τ becomes larger than that represented by the dotted line to improve the control ability. Also, it is possible to construct crosswise by negatively feeding the electrical quantity relating to the motoring torque also back to the braking torque control system.

Fig. 5 is a waveform diagram for explaining the operation of the elevator controlled by the arrangement of Fig. 1.

First, at the starting and accelerating time, the speed instruction SP and the speed feedback value SF are compared in the comparators $CP1$ and $CP2$. The motoring torque τ_{HM} is controlled in accordance with the deviation between the speed instruction SP and the speed feedback value SF by the primary voltage control device WR through the phase shifters $PS1$ and $PS2$. Consequently, the elevator speed ω increases following the speed instruction SP , and never fluctuates with the direction and value of the load. At this time, the current I_{HM} of the high speed induction motor HM is an alternating current in the positive and negative directions as shown at (b) in Fig. 5, and the acceleration of the elevator α varies as shown at (b) in Fig. 5.

Next, when the accelerated elevator reached the deceleration starting position before the set floor at the time t_d , the speed

instruction SP decreases depending on the position of the elevator as described above.

At this time, since the moment of inertia of the motor shaft is selected small, the elevator speed is scattered between δ_1 and δ_2 , depending on the weight ratio between the elevator car CA and the counter weight CW in an uncontrolled state. This is to be adjusted to follow the speed instruction SP as indicated by the arrow at (a) in Fig. 5 by the torque characteristic τ in Fig. 4. For example, in order to control the speed when it tends to δ_2 at a time such as when the elevator is unloaded running up, or heavily loaded running down at a speed ω_1 , a large torque is not necessary because the moment of inertia is small as described above. Moreover, since the gain of the torque characteristic in the region of a small speed deviation S is high, it is possible to approximate the elevator speed ω_1 to the speed instruction SP with a high accuracy. Consequently, the alignment of the lift with the destination floor can be made accurate.

In Fig. 5, 1 is suffixed to reference characters for the elevator load torque in the negative direction, while 2 is suffixed to the elevator load torque in the positive direction. For example, in the case of the load torque in the negative direction, the low speed induction motor LM is supplied with a DC braking current I_{LM1} because a braking torque is necessary for preventing overshoot, while in the case of the load torque in the positive direction such as δ_1 , the high speed induction motor HM is supplied with an acceleration current I_{HM2} but hardly with a DC braking current I_{LM2} because conversely the motoring torque is necessary at the deceleration time.

In this manner the elevator decelerates and at a time t_s at which the speed approaches zero the electromagnetic brake MB is operated. In this case the speed is sufficiently low, the acceleration α decreases as shown at (d) in Fig. 5, only very little vibration of the elevator car is produced, and the ride is comfortable.

In the embodiment of the present invention a first electric motor for producing a motoring torque may be any kind of electric motor. However, from considerations of structural simplicity and inexpensiveness, it is preferable to employ an induction motor with the primary voltage control by a thyristor.

As a second electric motor for producing braking torque, an induction motor with a DC braking control is most suitable for a similar reason. However, a DC motor may also be utilized.

Also, in the above embodiment a description has been made of the speed deviation in the speed feedback control as the torque control input. However, the present invention

is also applicable to the case of the feedback of the positional signal and the instruction of the torque itself.

WHAT WE CLAIM IS:—

1. An electric motor controlling system comprising an electric motor apparatus including a first motor portion and a second motor portion, each of the portions consisting of a motor or a motor winding, a first control unit for controlling a motoring torque generated by said first motor portion, a second control unit for controlling a braking torque generated by said second motor portion, means for generating a speed instruction signal, first control means for controlling said first control unit in accordance with the value of a difference between said speed instruction signal and a signal representative of an actual speed of said motor apparatus when said difference is positive, second control means for controlling said second control unit in accordance with the value of said difference when said difference is negative, and means for biasing at least one of said first and second control means so that the motoring torque and the braking torque are simultaneously generated in the region of a small value of said difference.
2. A system according to Claim 1, further comprising means for detecting an electrical quantity relating to the produced torque of at least one of said first and second motor portions and means for negatively feeding back an output of said detecting means to the control means associated with the other motor portion.
3. A system according to Claim 1, wherein said first control unit comprises thyristors connected between an AC power supply and said first motor portion.
4. A system according to Claim 1, wherein said second control unit comprises a controllable rectifier circuit connected between an AC power supply and said second motor portion.
5. A system according to Claim 4, wherein said controllable rectifier circuit comprises two thyristors connected in series on the respective sides of one of AC side terminals and two unidirectional elements connected in series on the respective sides of the other AC side terminal.
6. A system according to Claim 1, wherein said motor apparatus comprises a single induction motor having two windings.
7. A system according to Claim 1, wherein said speed instruction signal generating means comprises means for generating signal increasing with time, means for generating another signal as a function of the position of a load coupled to said motor apparatus, and means for receiving the two signals and preferentially delivering a lower



instruction SP decreases depending on the position of the elevator as described above. At this time, since the moment of inertia of the motor shaft is selected small, the elevator speed is scattered between δ_1 and δ_2 depending on the weight ratio between the elevator car CA and the counter weight CW in an uncontrolled state. This is to be adjusted to follow the speed instruction SP as indicated by the arrow at (a) in Fig. 5 by the torque characteristic τ in Fig. 4. For example, in order to control the speed when it tends to δ_2 at a time such as when the elevator is unloaded running up, or heavily loaded running down at a speed w_1 , a large torque is not necessary because the moment of inertia is small as described above. Moreover, since the gain of the torque characteristic in the region of a small speed deviation S is high, it is possible to approximate the elevator speed w_1 to the speed instruction SP with a high accuracy. Consequently, the alignment of the lift with the destination floor can be made accurate.

In Fig. 5, 1 is suffixed to reference characters for the elevator load torque in the negative direction, while 2 is suffixed to the elevator load torque in the positive direction. For example, in the case of the load torque in the negative direction, the low speed induction motor LM is supplied with a DC braking current I_{LM1} because a braking torque is necessary for preventing overshoot, while in the case of the load torque in the positive direction such as δ_1 , the high speed induction motor HM is supplied with an acceleration current I_{HM2} but hardly with a DC braking current I_{LM2} because conversely the motoring torque is necessary at the deceleration time.

In this manner the elevator decelerates and at a time t_s at which the speed approaches zero the electromagnetic brake MB is operated. In this case the speed is sufficiently low, the acceleration α decreases as shown at (d) in Fig. 5, only very little vibration of the elevator car is produced, and the ride is comfortable.

In the embodiment of the present invention a first electric motor for producing a motoring torque may be any kind of electric motor. However, from considerations of structural simplicity and inexpensiveness, it is preferable to employ an induction motor with the primary voltage control by a thyristor.

As a second electric motor for producing braking torque, an induction motor with a DC braking control is most suitable for a similar reason. However, a DC motor may also be utilized.

Also, in the above embodiment a description has been made of the speed deviation in the speed feedback control as the torque control input. However, the present invention

is also applicable to the case of the feedback of the positional signal and the instruction of the torque itself.

WHAT WE CLAIM IS:—

1. An electric motor controlling system comprising an electric motor apparatus including a first motor portion and a second motor portion, each of the portions consisting of a motor or a motor winding, a first control unit for controlling a motoring torque generated by said first motor portion, a second control unit for controlling a braking torque generated by said second motor portion, means for generating a speed instruction signal, first control means for controlling said first control unit in accordance with the value of a difference between said speed instruction signal and a signal representative of an actual speed of said motor apparatus when said difference is positive, second control means for controlling said second control unit in accordance with the value of said difference when said difference is negative, and means for biasing at least one of said first and second control means so that the motoring torque and the braking torque are simultaneously generated in the region of a small value of said difference.

2. A system according to Claim 1, further comprising means for detecting an electrical quantity relating to the produced torque of at least one of said first and second motor portions and means for negatively feeding back an output of said detecting means to the control means associated with the other motor portion.

3. A system according to Claim 1, wherein said first control unit comprises thyristors connected between an AC power supply and said first motor portion.

4. A system according to Claim 1, wherein said second control unit comprises a controllable rectifier circuit connected between an AC power supply and said second motor portion.

5. A system according to Claim 4, wherein said controllable rectifier circuit comprises two thyristors connected in series on the respective sides of one of AC side terminals and two unidirectional elements connected in series on the respective sides of the other AC side terminal.

6. A system according to Claim 1, wherein said motor apparatus comprises a single induction motor having two windings.

7. A system according to Claim 1, wherein said speed instruction signal generating means comprises means for generating signal increasing with time, means for generating another signal as a function of the position of a load coupled to said motor apparatus, and means for receiving the two signals and preferentially delivering a lower

one of the signal as said speed speed instruction signal.

5 8. A system according to Claim 1, wherein said motor apparatus comprises two induction motors forming said first and second motor portions, the induction motor for the second motor portion having a larger number of poles than that of the induction motor for the first motor portion.

9. An electric motor controlling system 10 constructed and arranged substantially as described herein with reference to and as shown in the accompanying drawings.

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