

PATENT SPECIFICATION

(11) 1219807

DRAWINGS ATTACHED

1219807

- (21) Application No. 30461/68 (22) Filed 26 June 1968
 (31) Convention Application No. 41001 (32) Filed 28 June 1967 in
 (33) Japan (JA)
 (45) Complete Specification published 20 Jan. 1971
 (51) International Classification H 02 p 7/48 7/74 B 66 b 1/06
 (52) Index at acceptance

H2J 18 1H1 1K1 1L1 1N1 6 7A 9D



(54) AN AC ELEVATOR CONTROLLING APPARATUS

(71) We, HITACHI LTD., a Japanese Body Corporate, of 4,1-chome, Marunouchi, Chiyoda-ku, Tokyo, Japan, do hereby declare that 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:—

This invention relates to an AC elevator controlling apparatus, and more particularly, it is directed to improvements in an AC elevator controlling apparatus by which an elevator cage is accelerated or decelerated by the torque which is produced in a stepped manner by a drive motor during the acceleration and/or during the deceleration.

An elevator equipment using an induction motor (usually, three-phase squirrel-cage induction motor or three-phase wound-rotor induction motor) for driving the traction sheave is commonly called an AC elevator, which has been employed extensively since it can be manufactured at low cost and has a simple and sturdy construction as compared with a DC elevator. However, the induction motor is difficult to control in comparison with a DC motor, and therefore it is technically very difficult to continuously produce the torque for effecting upward and downward motion.

Heretofore, therefore, it was impossible to eliminate completely certain torque variations during acceleration and deceleration, thereby sacrificing the quality of ride or the comfortable ride to a certain degree.

According to the invention, there is provided an AC elevator controlling apparatus, comprising a traction sheave having a rope hung thereon, an elevator cage which is attached to said rope for upward and downward movement, at least one induction motor for driving said traction sheave, and control means for said induction motor or motors, wherein the control means is adapted to enable said induction motor or motors to produce at least two different magnitudes of torque in stages and at least either the magnitude or interval of at least one torque produced at and after the second stage is so selected as to

restrain vibrations of the vertical vibration system of the elevator which have been caused by the torque produced in the previous stages. 50

The invention will now be described, by way of example, with reference to the accompanying drawings, in which: 55

FIGURE 1 is a diagrammatic view showing the entire arrangement of an AC elevator;

FIGURE 2 is a view showing the main control circuit incorporated in the apparatus according to an embodiment of this invention; 60

FIGURE 3 is a view showing the starting and speed-reduction control circuit;

FIGURE 4 is a view showing the call signal register circuit;

FIGURE 5 is a view showing the travelling direction selecting circuit; 65

FIGURE 6 is a view useful for explaining the operation of the position detecting device;

FIGURE 7 is a view showing an equivalent vibration system of the elevator cage; 70

FIGURE 8 is a view useful for explaining the single-stage torque control;

FIGURE 9 is a view useful for explaining the two-stage torque control;

Fig. 10 is a view useful for explaining the three-stage torque control; 75

Figs. 11, 12, 13 and 14 are views illustrating the apparatus according to a second embodiment of the present invention;

Figs. 15 and 16 are views useful for explaining the three-stage torque control and four-stage torque control, respectively; 80

Fig. 17 is a connecting diagram showing the apparatus according to a third embodiment of this invention; 85

Fig. 18 is a side view showing an example of the load detecting device;

Figs. 19, 20 and 21 are views useful for explaining torque variations when a squirrel-cage induction motor is used; 90

Fig. 22 is a view showing an example of the notch interval setting; and

Fig. 23 is a view illustrating the actual elevator operation.

Referring to Fig. 1, there is shown the entire arrangement of a common AC elevator 95

to which the present invention is applied. In the drawing, the reference numeral 1 represents a rope hung on a traction sheave 2, the rope 1 having a counter-weight 3 attached to one end and an elevator cage 4 affixed to the other end. The reference numeral 5 denotes a simple rod portion spring interposed between the rope 1 and the cage 4, 6 a reduction gear means, 7 an electromagnetic brake means, 8 a low-speed induction motor and 9 a high-speed induction motor. In the case of Fig. 1, use is made of two induction motors whose numbers of poles are different (24 poles for the low-speed one and 6 poles for the high-speed one). However, it is also possible to employ a pole change type double-speed induction motor.

Fig. 2 shows the control circuit for the motors shown in Fig. 1. Terminals U_1 , V_1 , W_1 and terminals U_2 , V_2 , W_2 are connected with U_1 , V_1 , W_1 and U_2 , V_2 , W_2 of Fig. 1, respectively. R_1 and R_2 are control resistors for controlling the high-speed induction motor 9 which are constituted by resistor elements R_{11} , R_{12} , R_{13} and R_{21} , R_{22} , R_{23} , respectively. Main contactors 20 and 21 each consisting of three contact pieces are connected in parallel with the control resistors R_1 and R_2 , respectively.

The reference numerals 13 and 14 represent main contactors for speed change. For the high-speed operation, the contactor 13 is turned on, while the other main contactor 14 is turned on for the low-speed operation. The reference numerals 11 and 12 denote main contactors for changing the travelling direction. For the upward movement of the elevator cage, the main contactor 11 is turned on, while the other main contactor 12 is turned on for the downward movement of the elevator cage. The reference numeral 10 indicates a main contactor for power source. R_3 is a control resistor for controlling the low-speed induction motor 8 and which is constituted by resistor elements R_{31} , R_{32} and R_{33} . A main contactor 22 comprising three contact pieces is connected in parallel with the resistor R_3 .

Referring to Fig. 3, T_1 , T_2 and T_3 are timer relays, 20M, 21M, 22M and 10M are coils for the main contactors 20—10 shown in Fig. 2 respectively, and 13M, 14M and 11M, 12M are also coils. The reference numeral 92 represents a speed reduction commanding relay which is adapted to be energized at the speed reduction commanding point. During upward movement, the relay 92 is energized by the fact that a position detecting device P_{11} is turned on when the cage reaches the speed reduction commanding point, and during downward movement, it is energized by the fact that the position detecting device P_{12} is turned on. In either case, the relay 92 holds itself with a self-holding contact 92—1 closed. A position detecting

device P_{20} is opened upon arrival of the elevator cage at the rest position of each floor. Fig. 4 is a circuit diagram of a call signal registering device, wherein 1C—4C represents contacts which are adapted to be closed by depressing a "destination" button, 41, 42, 43 and 44 are call signal registering relays for the 1st to 4th floors, respectively, CL a door closing pushbutton switch, OP a door opening push-button switch, and 100 a start preparation relay. Referring to Fig. 5, MB is a release coil for the electromagnetic brake, 30 a relay for automatic closure, DC a timef condenser, and DR a timer resistor. The reference numeral 40 represents a door closure confirming relay which is energized when the door of each floor is closed to close door switches DS_1 — DS_4 and the cage side door is closed to close a cage door switch GS.

Numerals 61 and 62 represent travelling direction selecting relays, and SR_1 and SR_2 short-circuit preventing resistors. The reference numerals 51 to 54 denote floor position detecting relays each of which is energized by the fact that each of position detecting devices P_{30} to P_{33} is turned on when the cage arrives at each floor. Fig. 6 is a view useful for explaining the operation of each position detecting device, wherein the cage positions are vertically shown, P_{11} , P_{12} , P_{30} — P_{33} have their contacts closed in sections marked, and P_{20} is closed when the cage reaches each floor level 1FL—4FL.

In Figs. 3, 4, 5, 13 and 17, there are shown a number of make contacts and break contacts. An example of the symbol indicating a make contact is one designated 92—1 in Fig. 3, and a make contact is closed upon energization of the contactor or the relay associated therewith. While, an example of the symbol indicating a break contact is one designated 10—1 in Figure 3, and a break contact is opened upon energization of the contactor or the relay associated therewith. A plurality of contacts associated with a certain contactor or relay are indicated by reference numerals with suffixes. (For example, the contacts of the relay 40 are indicated by 40—1, 40—2, 40—3 etc.).

Assume now that contact 3H (Fig. 4) is closed by the fact that the floor calling button at the third floor is depressed when the elevator cage is stopped at the first floor.

Upon closure of the contact 3H, the call signal registering relay 43 is immediately energized and self-held through a circuit of (+)→43→43—3→53—1→(—). Contact 53—1 is closed since the elevator cage is now located at the first floor.

In Figure 5, when the relay 43 is energized, the contact 43—4 is closed and an upward direction selecting relay 61 is energized through a circuit (+)→61→62—4→ SR_1 →(—) so that a contact 61—1 thereof (Fig. 3) is closed. Subsequently, if the door

closing push-button switch CL (Fig. 4) is depressed by a passenger or operator, the start preparation relay 100 is energized through a circuit $(+) \rightarrow 100 \rightarrow 92 \rightarrow 4 \rightarrow CL \rightarrow (-)$ and self-held with a contact 100—3 thereof closed. Upon energization of the relay 100, the door of an elevator hall and the cage door begin to close, although not shown in the drawing.

When a contact 100—2 (Fig. 3) of the relay 100 is closed as a result of the energization of the contact 100, a circuit $(+) \rightarrow 11M \rightarrow 12-2 \rightarrow 61-1 \rightarrow 92-2 \rightarrow 100-2 \rightarrow (-)$ is established in Fig. 3, so that the operation coil 11M of the main contactor is energized. Thus, the contact 11—1 is closed, but the operation coil 10M of the main contactor is not energized in so far as the contact 40—1 is opened. If the doors on the respective floors are closed to close the door switches DS_1 — DS_4 and the elevator cage door is closed to close the door switch GS, then the door closure confirming relay 40 is energized. The energization of the relay 40 causes the contact 40—1 to be closed, and thus a circuit $(+) \rightarrow 10M \rightarrow 40-1 \rightarrow 11-1 \rightarrow (-)$ is established through which the main contactor operation coil 10M is energized.

At this time, the contact 10—6 (Fig. 5) is closed so that the release coil MB is energized to release the electromagnetic brake. On the other hand, the operation coil 13M of the main contactor for high-speed operation has already been energized through the contact 100—1 in Fig. 3 concurrently with the energization of the start preparation relay 100, and therefore when the main contactor operation coil 10M is energized to close the contactor 10 (Fig. 2), the high-speed induction motor 9 is enabled to start and produce a torque which is $1/3$ of the full torque with the control resistors R_1 and R_2 connected in series therewith, as will be seen from Figs. 1 and 2. On the other hand, the timer relay T_1 is de-energized since the contact 10—1 is opened simultaneously with the energization of the main contactor coil 10M, so that contact T_1 —1 closed after a predetermined lapse of $2\pi/3\omega$ seconds. Thus, the main contactor operation coil 20M is energized so that the contactor 20 is closed and the control resistor R_1 is short-circuited (Fig. 2).

When the control resistor R_1 is short-circuited as described above, the induction motor 9 produces a torque twice as large as the previous one or $2/3$ of the full torque to thereby accelerate the elevator cage.

Upon energization of the main contactor coil 20M, a contact 20—1 is opened so that the time relay T_2 is de-energized, but the contact T_2 —1 is not immediately closed. That is, the contact T_2 —1 is closed after a predetermined time of $2\pi/3\omega$ seconds, whereupon the main contactor coil 21M is ener-

gized, where, the symbol ω denotes a natural angular frequency of the vertical vibration system of the elevator cage. Upon energization of the main contactor coil 21M, the control resistor R_2 is short-circuited through the main contactor 21 of Fig. 2, with a result that the torque produced by the motor 9 is increased to be three times as much as the previously produced torque, that is, it becomes the full torque.

Now, if the elevator cage arrives at the speed-reduction commanding point which is set a predetermined distance short of the third floor, the position detecting device P_{11} in Fig. 3 is turned on (see also Fig. 6), and the speed-reduction commanding relay 92 in Fig. 3 is energized through a circuit $(+) \rightarrow 92 \rightarrow 10-5 \rightarrow 61-2 \rightarrow P_{11} \rightarrow 43-2 \rightarrow (-)$ so that it is self-held with the self-holding contact 92—1 closed. The contact 92—2 of Fig. 3 is opened through the energization of the speed-reduction commanding relay 92, and the main contactor coil 11M for upward movement is energized through contact 10—4 and P_{20} .

The start preparation relay 100 of Fig. 4 is de-energized concurrently with the opening of the contact 92—4 so that the contact 100—1 thereof is opened, with a result that the main contactor coil 13M for high-speed operation is de-energized. The de-energization of the contactor coil 13M causes the main contactor 13 to open and causes the contact 13—2 in Fig. 3 to close. The closure of the contact 13—2 energizes the coil 14M of the main contactor 14 for the low-speed operation. As a result, the low-speed induction motor 8 is connected with the power source through the main contactor 10 for the power source, main contactor 11 for upward movement, main contactor 14 for low-speed operation and control resistor R_3 . Consequently, the motor 8 is enabled to operate as an induction generator of which the regenerated power is returned to the power source, so that $1/2$ of the predetermined regenerative braking torque τ_b is produced. Concurrently with the energization of the main contactor coil 14M, the contact 14—1 thereof (Fig. 3) is opened so that the time relay 3 is de-energized. The time relay 3 will have the contact T_3 —1 thereof closed after the set time π/ω so that the main contactor coil 22M will be energized to close the main contactor 22 in Fig. 2. Thus the control resistor R_3 is short-circuited. Consequently, the braking torque is further increased to become equal to the predetermined braking torque τ_b .

In this way, the speed of the induction motor 8 is reduced so that the elevator cage is enabled to approach the destination floor with a low speed. At the destination floor, the position detecting device P_{20} is opened so that the main contactor coil 11M is de-energized (see Fig. 6).

As a result, the contact 11—1 is opened, whereupon the coil 10M of the main contactor is de-energised. Thus, in Fig. 2, the main contactor 10 is opened to disconnect the motor 8 from the AC power source, and in Fig. 5 the contact 10—6 is simultaneously opened so that the release coil MB of the electromagnetic brake 7 is de-energized. Consequently, a braking force is mechanically produced by the electromagnetic brake 7 to thereby stop the elevator cage at the third floor.

Upon arrival of the elevator cage at the third floor, the position detecting device P_{31} is turned on to energize the position detecting relay 53 so that a contact 53—3 of the relay 53 is closed while a contact 53—1 thereof is opened. Thus, upward direction selecting relay 61 (Fig. 5) and call signal registering relay 43 (Fig. 4) are de-energized.

Although, in the foregoing discussion, description has been made of the case where the upward movement of the elevator is effected by depressing the call button at the third floor, it will be apparent that similar control can be achieved when upward movement is effected by depressing "destination" button or buttons provided in the cage or when downward movement is effected in accordance with the call signal registration, and therefore further description will be omitted.

In the foregoing, the torque produced by the high-speed induction motor 9, when it is to be started, is controlled by means of the time relays T_1 and T_2 to become $1/3$ and $2/3$ of and equal to the full torque at the time 0, $2\pi/3\omega$ and $4\pi/3\pi$ respectively.

When the speed is to be reduced, a torque which is $1/2$ of the predetermined braking torque τ_b is produced, and it is made equal to the predetermined braking torque τ_b after π/ω seconds.

Such control is based on the following principle, whereby vibration tending to occur during the starting is restrained. Description will be made of the case of acceleration hereinbelow, but it is quite apparent that during deceleration similar control can be achieved.

The result of the research conducted by the inventors shows that in the elevator system such as shown in Fig. 1, an upward and downward vibration system is constituted by the motor portion, rope, elevator cage and so forth whereby vibrational acceleration and deceleration are caused during the starting and stopping so that the quality of ride is deteriorated.

It is considered that this is because the elevator cage constitutes a vibration system similar to a spring pendulum supported by virtue of the rigidity of the rope and a simple rod spring since the rope used in a rope type elevator is longitudinally flexible.

Fig. 7 shows an equivalent vibration system of the above system.

In Fig. 7, K is the combined spring constant, m_1 the motor side inertial mass reduced to the periphery of the traction sheave, m_2 the cage side mass, F the external force corresponding to the motor torque which is reduced to the sheave periphery, and X_1 and X_2 displacements of the masses m_1 and m_2 respectively.

Since the counter weight 3 is suspended in the form of a well-bucket with the traction sheave held between itself and the cage 4, it has very little effect on the cage 4 in respect of vibration.

Assume that the torque τ as shown in Fig. 8(a) is imparted to the above vibration system by the induction motors 8 and 9. In case the mechanical system has no response delay, the acceleration a of the mass m_2 (cage) acting on the equivalent vibration system shown in Fig. 7 is given by

$$a = \frac{F}{m_1 + m_2} (1 - \cos \omega t) \quad (1)$$

Here, the relationship between the torque τ and the external force F is as follows:

$$F = \frac{n_g \tau}{r} \quad (2)$$

n_g : reduction ratio of the reduction gear means

r : radius of the traction sheave

t : time

Since n_g and r are constants, a relation $F \propto \tau$ holds.

Thus, there occurs a vibrational acceleration with a maximum value of $\frac{2F}{m_1 + m_2}$

and a minimum value of 0, which is graphically shown in Fig. 8(b). (In this case, the attenuation of the vibration is omitted.)

Obviously, the speed of the elevator cage varies as shown in Fig. 8(c), resulting in a great deterioration of the quality of ride.

The natural angular frequency ω of the vertical (upward and downward) vibration system of the elevator cage can be determined by

$$\omega^2 = K \frac{m_1 + m_2}{m_1 m_2} \quad (3)$$

K : combined spring constant depending upon the rope and simple rod portion spring 5

The aforementioned natural angular frequency ω varies depending upon the type of elevator, the weight of a load, the position

of the elevator cage (the effective length of the rope) and so forth. In the case of an ordinary elevator system, the natural vibrational frequency thereof is in the range of 2 to 3 C/S, and therefore the natural angular frequency may be considered to be in the range of 12.5 to 37.6 rad/sec.

If a torque (A) having a magnitude $\tau/2$ is applied at a point of time 0 and a torque (B) having a magnitude τ is applied π/ω seconds after said point of time as shown in Fig. 9, then the acceleration α_1 of the mass m_2 resulting from the application of the torque (A) is given by

$$\alpha_1 = \frac{\frac{1}{2}F}{m_1 + m_2} (1 - \cos \omega t) \quad (4)$$

and the acceleration of the mass m_2 resulting from the application of the torque (B) is given by

$$\alpha_2 = \frac{(F - \frac{1}{2}F)}{m_1 + m_2} \cdot \{1 - \cos (\omega t - \pi)\} \quad (5)$$

From equations (4) and (5), it will be noted that the acceleration α of the elevator cage 4 which occurs subsequent to the point of time π/ω becomes as follows:

$$\alpha = \frac{\frac{1}{2}F}{m_1 + m_2} \times \left[3 - \left\{ \cos \omega t + \cos \left(\omega t - \frac{2\pi}{3} \right) + \cos \left(\omega t - \frac{4\pi}{3} \right) \right\} \right] = \frac{F}{m_1 + m_2} \quad (7)$$

That is, as in the case of two-stage torque control, a constant acceleration including no vibrational component is produced after $4\pi/3\omega$ from the point of time 0, and the acceleration occurring prior to the point of time $4\pi/3\omega$ varies smoothly. Fig. 10 shows the characteristics for this case, wherein the torque is indicated by (A), (B) and (C), the vibrational accelerations produced through application of the torque of $\tau/3$, $2\tau/3$ and τ by α_1, α_2 and α_3 respectively, and the resultant acceleration of the cage by α .

Figs. 2 and 3 show the case where the torque is changed in three stages. In this case, the torque which is $1/3$ of the full torque τ is produced at the point of time 0 by connecting the control resistors R_1 and R_2 in series with the high-speed induction motor 9. At this time, a vibration with the acceleration α_1 is produced, as shown in Fig. 10(b).

After $2\pi/3\omega$ seconds, the time relay T_1 is de-energized to short-circuit the control resistor R_1 so that the torque produced by the motor 9 is increased up to $2\tau/3$, with a result that a vibration with the acceleration α_2 is produced. Further, after $4\pi/3\omega$ seconds, the time relay T_2 is de-energized to short-

$$\alpha = \alpha_1 + \alpha_2 = \frac{F}{m_1 + m_2} \quad (6)$$

Fig. 9 shows the above relationships, wherein the torque (A) and the torque (B) are shown at (a) and (b), the accelerations α_1 and α_2 at (c) and (d), and the resultant acceleration α which the elevator cage 4 undergoes at (e), respectively.

From Fig. 9, it is clear that the acceleration α of the elevator cage 4 increases smoothly between the points of time 0 and π/ω and assumes a constant value after the point of time π/ω , resulting in a completely non-vibrational acceleration.

Although, in the foregoing, description has been made of the case of acceleration, what has been described above can also be applied to the case of deceleration.

Description will now be made of the case of three-stage torque control.

If a torque having a magnitude of $\tau/3$ is applied at a point of time 0, a torque having a magnitude of $2\tau/3$ after $2\pi/3\omega$ seconds from said point of time, and a torque having a magnitude of τ after $4\pi/3\omega$ seconds from said point of time by the induction motor 9, the acceleration α of the mass m_2 which occurs at an interval subsequent to the point of time $4\pi/3\omega$ is given by

circuit the control resistor R_2 so that the generated torque becomes the full torque, with a result that a vibration with the acceleration α_3 is produced.

In this way, the acceleration is smoothly increased between the points of time 0 and $4\pi/3\omega$, and beyond the point of time $4\pi/3\omega$, it assumes a constant value, as shown in Fig. 10(c). It is quite obvious that in the case of deceleration, too, the vibration produced can be restrained by suitably setting the time for time relay T_3 .

In the foregoing example, description has been made of the case where the torque is changed in three stages. In practice, two-stage change is also satisfactory. Especially in the case of an elevator using two motors of different speeds, the low-speed motor 8 is driven to produce a torque of $\tau/2$ at the starting, and the high-speed induction motor 9 is driven to produce the torque τ in π/ω seconds, thereby restraining the vibrational acceleration, as shown in Fig. 11. In an attempt to start the elevator merely by means of the high-speed motor 9, it is only required that the control resistor be connected with the motor 9 so that a torque which is $1/2$ of the full torque is produced at the point of

time 0, with the control resistor R_2 omitted, and the resistor R_1 be short-circuited after π/ω seconds so that the full torque τ is produced, as shown in Fig. 12.

Referring to Figs. 13 and 14, there is shown another example for effecting three-stage torque control, wherein during the starting, the torque is changed by the use of the high-speed motor 9 and low-speed motor 8. Elements indicated by the same reference numerals and symbols as in Figs. 2 and 3, achieve the same functions as those shown in Figs. 2 and 3, and the remaining control circuits are similar to those of Figs. 4 and 5.

When elevator doors are closed and the contact 40-1 is closed, at the point of time 0, the coil 10M is energized to close the main contactor 10 for the source in Fig. 14. Therefore, if a call signal requesting the upward movement of the elevator has been registered, the main contactor 11 has been closed, so that the low-speed motor 8 is started to produce a torque which is $1/3$ of the rated torque τ , with the control resistor R_3 connected in series therewith. After $2\pi/3\omega$, the time relay T_1 is de-energized, and upon closure of a contact T_1-1 thereof, the main contactor operation coil 22M is energized through a circuit $(P) \rightarrow 22M \rightarrow 14-2 \rightarrow 92-7 \rightarrow T_1-1 \rightarrow (N)$. Thus, the control resistor R_3 is short-circuited by the main contactor 22 so that the motor 8 produces a torque which is $2/3$ of the rated torque τ . After the lapse of $4\pi/3\omega$, the time relay T_2 has a contact T_2-1 closed so that a circuit $(P) \rightarrow 13M \rightarrow 92-5 \rightarrow T_2-1 \rightarrow (N)$ is established through which the main contactor coil 13M is energized. The energization of the coil 13M results in the contactor 13 being closed and the contact 13-2 being opened so that the coil 14M is de-energized to open the contactor 14 in Fig. 14. Thus,

the low-speed motor 8 is disconnected from the power source, while the high-speed motor 9 is connected with the power source to produce the rated torque τ .

In deceleration, the deceleration commanding relay 92 is energized when the cage reaches the deceleration point, so that contacts 92-5 and 92-6 are opened. The opening of the contact 92-5 results in de-energization of the coil 13M so that the contactor 13 of Fig. 14 is opened and the contact 13-2 of Fig. 13 is closed. The energization of the coil 14M results in the main contactor 14 being closed to enable the low-speed motor 8 to act as an induction generator. The power generated by the motor 8 is returned to the power source, and thus a torque which is $1/2$ of the predetermined regenerative braking torque τ_b is produced.

After the lapse of the time, π/ω seconds, of the time relay T_3 , a contact T_3-1 thereof is closed so that a circuit $(P) \rightarrow 22M \rightarrow 14-2 \rightarrow T_3-1 \rightarrow 92-6 \rightarrow (N)$ is established through which the coil 22M is energized to short-circuit the control resistor R_3 of Fig. 14 with the contactor 22.

At this time, the regenerative braking torque of the motor 8 is increased to τ_b to further reduce the speed of the elevator cage.

The acceleration and deceleration can be smoothly changed under the above control during the accelerating and decelerating operation.

In the case of a three-stage torque change, a torque of $\tau/3$ is produced by the induction motor at the point of time 0, a torque of $2\tau/3$ at the point of time θ/ω , and a torque τ at the point of time $2\theta/\omega$ where the symbol θ denotes a phase angle. Thus, the acceleration given to the mass m_2 after the point of time $2\theta/\omega$ is given by

$$a = \frac{\frac{1}{3} \cdot F}{m_1 + m_2} [3 - \{\cos \omega t + \cos(\omega t - \theta) + \cos(\omega t - 2\theta)\}] \quad (8)$$

The components within $\{ \}$ represent periodically changing vibrational components, which can be considered as the real parts of the following simple harmonic motion vectors rotating at phase angles of 0, θ and 2θ with the same angular frequency, as shown in Fig. 15(b):

$$A = \cos \omega t + j \sin \omega t$$

$$B = (\cos \theta - j \sin \theta) (\sin \omega t + j \sin \omega t)$$

$$C = (\cos 2\theta - j \sin 2\theta) (\cos \omega t + j \sin \omega t)$$

Therefore, the vibrational component occurring in the mass m_2 can be determined by

the amplitude of the combined vector $\dot{Y}$ shown in Fig. 15(b).

$$|\dot{Y}| = |1 + \cos \theta - j \sin \theta + \cos 2\theta - j \sin 2\theta| \quad (10)$$

If θ is changed in the range of $0^\circ - 360^\circ$, as shown in Fig. 16(a). At $\theta = 120^\circ$ and then the locus of said vector $\dot{Y}$ will become 240° , $\dot{Y} = 0$.

From this, it will be noted that in the case of a three-stage control, the vibration can be completely cancelled by setting θ to 120° or 240° , Fig. 3 shows the case where

5 $\theta = -\pi$. The natural frequency of vibration

of an elevator system varies substantially depending upon the operational conditions (the position of the elevator cage, the number of passengers, and so forth). As will be apparent from Fig. 16(a), the amplitude of the superposed vibration can be reduced down to $\frac{1}{3}$ or less than that for the case of one-stage

control when θ ranges from $-\pi$ to $-\pi$

or $-\pi \leq \theta \leq -\pi$. From a practical stand-

15 point, therefore, a considerable vibration restraining effect can be produced without compensating for changes in the operational conditions, if θ is set as $\theta = \pi$ at the mean frequency of vibration f_{mean} . More specifically, the mean natural frequency of vibration f_{mean} of the elevator system is determined from the maximum natural frequency of vibration f_{max} that will occur when the cage with no load is positioned at the upper terminal and the

25 minimum natural frequency of vibration f_{min} that will occur when the cage with full load is positioned at the lower terminal.

$$f_{\text{mean}} = \frac{f_{\text{max}} + f_{\text{min}}}{2} \quad (11)$$

$$\alpha = \frac{\frac{1}{2} \cdot F}{m_1 + m_2} [4 - \{\cos \omega t + \cos \omega t (\omega t - \theta) + \cos (\omega t - 2\theta) + \cos (\omega t - 3\theta)\}] \quad (8')$$

65 The combined amplitude of the variation is represented by the combined amplitude of

Then the notch interval t_n for the torque is selected as follows: 30

$$t_n = \frac{1}{2} T_{\text{mean}} \quad (12)$$

where T_{mean} is the natural cyclic period of vibration corresponding to the mean natural frequency of vibration f_{mean} (in Fig. 16(a), $\theta = \pi$). Thus the vibration of the elevator system can be reduced by a factor of $\frac{1}{3}$ or less substantially over the entire area thereof irrespective of a change in the natural cyclic period of vibration of the elevator system. 35 40

Consider an ordinary elevator of which the natural frequency of vibration varies in a range of 2 to 6 cycles/sec, for example. The mean natural cyclic period of vibration T_{mean} thereof turns out to be $T_{\text{mean}} = 0.25$ sec. Therefore, if, the notch interval t_n is set at $t_n = \theta / \omega = \frac{1}{2} \times 0.25 = 0.125$ sec., then

$\theta' = 2\pi \times 2 \times 0.125 = \pi$ when the minimum natural frequency of vibration $f_{\text{min}} = 2$ cycles/sec., and $\theta'' = 2\pi \times 6 \times 0.125 = -\pi$ 50

when the maximum natural frequency of vibration $f_{\text{max}} = 6$ cycles/sec. In this way, the combined amplitude vibration can be reduced by a factor of $1/3$ or less over the entire range of the natural frequency of vibration of the elevator. 55

Description will now be made of the case where the torque is uniformly divided into four components and the respective notch turn-on phases are $0, \theta, 2\theta$ and 3θ . 60

The vibration occurring at the mass m_2 is given by

$$|Y| = 1 + \cos \theta - j \sin \theta + \cos 2\theta - j \sin 2\theta + \cos 3\theta - j \sin 3\theta \quad (13)$$

70 and the locus of the combined amplitude becomes as shown in Fig. 16(b). Thus, the combined amplitude becomes 0 at $\theta = -\pi$ and $-\pi$. In this case, therefore, by setting

75 θ as $\theta = \pi$, the vibration can be completely restrained. Even if the natural frequency of vibration is changed over a considerable

range, the combined amplitude can be decreased down to about $\frac{1}{3}$ or less than that for the case of one-stage control.

By the same reasoning, if a torque is uniformly divided into n components ($n \geq 2$) and it is changed in multi-stage by an amount of τ/n at a constant time interval θ/ω seconds (notch interval), then the acceleration α which occurs at the mass m_2 after $(n-1)\theta/\omega$ seconds will generally be given like Equation (8), by 80 85

$$\alpha = \frac{\frac{1}{n}F}{m_1 + m_2} [n - \dot{Y}] \quad (8'')$$

and the combined amplitude of the vibration will be represented by

$$|\dot{Y}| = \left| \sum_{i=0}^{n-1} \cos i\theta - j \sum_{i=0}^{n-1} \sin i\theta \right| \quad (10'')$$

5 From this, it will be noted that it is always possible to prevent any vibration from occurring by setting each notch interval to even multiples of $2\pi/n$ (θ = even multiples of $\frac{2\pi}{n}$).

10 In the case where the natural frequency vibration varies depending upon the operational conditions as in an actual elevator, each notch interval is selected so as to be $\frac{1}{2}$ of the mean natural frequency of vibration, in view of the fact that the combined amplitude described here above becomes symmetrical at $\theta = \pi$. Thus, no vibration occurs at the point corresponding to the set cyclic period of vibration in the case where the torque is divided in even stages, so that the combined amplitude becomes about $1/n$ of that for the case of one-stage control, regardless of a change in the cyclic period.

25 In the case of an odd division, the combined amplitude becomes $1/n$ of that for the case of a one-stage control at the mean natural frequency of vibration, whereas at a natural frequency of vibration other than the mean one, the combined amplitude always becomes smaller than $1/n$ of that for the case of a one-stage control, irrespective of variations in the natural frequency of vibration.

30 In the foregoing, description has been made of the case where the torque is uniformly divided into n components and the notch interval t_n is also made constant. However, in case $n=3$, a similar vibration restraining effect can be produced by changing the notch interval t_n for each notch, whether

40 or not each torque component is uniform. Assume now that the sectional area of the ropes 1 having the elevator cage attached thereto is A , Young's modulus is E , the effective length of the ropes is l , and the number of the ropes is n . Then the equivalent spring constant K in Fig. 7 is represented by

$$K = \frac{EA}{l} \cdot n \quad (15)$$

Thus, the ideal notch interval t_n for a two-

stage control can be calculated from Equations (3) and (15) as follows:

$$t_n = \frac{\pi}{\omega} = \pi \sqrt{\frac{1}{E \cdot A \cdot n \left(1 + \frac{m_2}{m_1}\right)}} \cdot m_2 l \quad (16)$$

From this equation, it will be seen that the vibrational acceleration of the elevator cage varies depending upon the effective length l of the ropes and the mass m_2 of the elevator cage. In order to be able to produce a vibration restraining effect under any operational condition, it is required that the notch interval t_n be changed in accordance with variations of the effective length l of the ropes and the mass m_2 of the cage.

Fig. 17 is a diagrammatical view showing another embodiment of the present invention, wherein the notch interval t_n is changed in accordance with the effective length l of the ropes.

By depressing a start button switch ST of the elevator cage, the coil 10M is energized by an AC power source AC through a rectifier RE so that the main contactor 10 is turned on. Consequently, the induction motor 9 is connected with a three-phase power source U, V, W through control resistor R_1 to produce a torque which is $1/2$ of the normal or rated torque.

On the other hand, the contact 10-1 is opened so that the relay T_1 is disconnected from the power source. Contact T_1-1 of the relay T_1 is not closed until a predetermined period of time T_0 lapses, since capacitors CC_1-CC_5 are connected in parallel therewith. Upon closure of the contact T_1-1 , the contactor coil 20M is energized so that the main contactor 20 is closed to short-circuit the control resistance R_1 . As a result, the induction motor 9 produces the rated torque, whereby the acceleration is further increased.

The period of time T_0 for the time relay T_1 corresponds to the notch interval, and the capacitors CC_1-CC_5 are connected or disconnected depending upon the position of the elevator cage.

This is carried out by upwardly or downwardly moving a movable segment P_0 into or out of contact with fixed segments P_1 to P_5 by means of a floor controller FC which is adapted to be moved in synchronism with the elevator cage. For the above purpose, use may be made of the contacts of the position detecting relays P_{30} to P_{35} described earlier in connection with Fig. 5.

In the state shown in the drawing, the elevator cage is positioned at the first floor, and therefore the effective length l of the ropes is a maximum so that all of the capacitors CC_1-CC_5 are connected in

parallel with the relay T_1 . Thus, by selecting the capacitance of each capacitor to satisfy Equation (16) in accordance with the effective length l of the ropes, vibration can be prevented from occurring on the basis of the principle of this invention.

Consider the case where the elevator cage is located at the uppermost floor (fifth floor in the present example). In such case, the effective length of the ropes becomes the shortest this length is denoted by l_1 . From Equation (16), therefore, it is apparent that the notch interval t_n should be minimum. The movable segment P_0 is disposed in contact with only the fixed segment P_1 , so that only the capacitor CC_1 is connected in parallel with the relay T_1 to minimize the notch interval t_n .

With the capacitances of the intermediate capacitors being sequentially changed, the vibrational acceleration of the elevator can be restrained at any position.

In this case, it will be seen from Equation (16) that if the capacitor CC_1 at the uppermost floor is of a proper value, the capacitance of the parallel capacitors at an intermediate floor i or $\Sigma C_i = C_1 + C_2 + \dots + C_i$ may be set to satisfy the following equation:

$$\Sigma C_i = C_1 \sqrt{\frac{l_1}{l_i}} \dots \dots \quad (17)$$

In the foregoing discussion, description has been made of the attempt to compensate for variations in the spring constant K stemming from variations of the effective length l of the ropes. However, it will be seen from Equation (16) that the notch interval to be set should also vary with variations of the cage mass m_2 resulting from change of the load. In a geared elevator with a high reduction gear ratio such as AC elevator, the mass m_1 of the motor and speed-reducing mechanism portion is several times (normally ten times or more) as great as the cage mass m_2 . Thus, by changing the notch interval in proportion to $\sqrt{m_2}$, with a change of the term m_2/m_1 in Equation (16) neglected, it is possible to eliminate the influence of load variations in the same manner as the above.

A method for detecting the cage load is to use a weighing apparatus or a load detecting device and convert the output thereof to mechanical displacement, or electric signals, thereby achieving the aforementioned purposes.

Fig. 18 shows an example of a load detecting device, wherein the expansion and contraction of the simple rod portion spring 5 are detected by means of a differential transformer type position detector DD constituted by a movable core Mc_1 and a fixed core Sc_1 and having input terminals T_{11} , T_{12} , so that an

output corresponding to the load is obtained across output terminals T_{01} and T_{02} of the detector. The output at T_{01} and T_{02} is used for adjusting the time delay for the relay T_{11} , systems for adjusting the time of relays being well known.

In the present invention, it is preferable that the torque characteristics produced by the motor be flat as shown in Figs. 9 and 10. This is because the torque should be changed in a stepped manner for a short period of time in the starting and thereafter free acceleration should be effected. A great change in the torque during the free acceleration (this corresponds to the short-circuiting of the control resistors R_1 and R_2 in Fig. 2) will result in an excess or shortage of the acceleration so that the acceleration time becomes irregular, thus deteriorating the quality of ride. In general, with a wound-rotor induction motor, the torque is considerably changed with an increase in speed. Therefore, care should be taken to restrain such torque variations in the present invention.

In contrast, the squirrel-cage induction motor is well suited to the present apparatus since the torque characteristics thereof remain flat for a large slip as shown in Fig. 19. The motor shown in the drawing is a pole change motor whose number of poles can changeably be set to 24 or 6 thereby achieving two-stage torque control.

At the starting, the motor is driven with the number of poles set to 24, so that a torque which is $\frac{1}{3}$ of the rated torque τ is produced. In this case, the motor is accelerated in such a manner as to follow the curve (A). If the number of poles is changed to 6 after the lapse of π/ω seconds, then there is produced the rated torque τ , and the motor is accelerated along the curve (B). In this case, the motor is freely accelerated until the torque produced thereby becomes equally balanced with respect to the load torque beyond the point of time π/ω sec., and the acceleration is effected with a substantially constant torque. For speed reduction, the number of poles of the motor is switched to 24, and the control resistors are inserted (as shown in Figs. 2 and 14). Thus a torque is $\frac{1}{2}$ of the full braking torque τ_b is produced (curve (C)), and after π/ω seconds the rated braking torque τ_b is produced (curve (A)). In this case, too, the torque is maintained constant as in the case of acceleration, thus resulting in improved control.

Fig. 20 shows the case where use is made of a squirrel-cage induction motor to achieve three-stage torque control. At the starting, the control resistors are connected with the low-speed motor (24 poles) to produce a torque which is $1/3$ of the rated torque, so that the motor is accelerated along the curve (A). After $\pi/3\omega$ seconds lapsed, the control

resistors are short-circuited so that the motor is enabled to produce a torque which is $2/3$ of the rated torque and accelerated along the curve (B). Finally, after $4\pi/3\omega$ seconds, the induction motor is switched to the high-speed motor with 6 poles, which produces a rated torque and is accelerated along the curve (C).

For speed reduction, similar control can be achieved, as described earlier in connection with Figs. 13 and 14.

Fig. 21 shows the case where use is made of a high-speed squirrel-cage motor to control the magnitude of torque in three stages. Such case has already been described in connection with Fig. 3 (description of speed reduction was omitted).

In the foregoing discussion, the delay in operation of the electromagnetic brake 7 was not considered. In practice, however, an elevator to be stopped is held by the brake 7 (Fig. 1). Therefore, about 0.1–0.15 sec., with two-stage control, the second stage torque will be produced after a lapse of time which is the sum of t_n (notch interval) + T_{ms} (delay time), from the moment that the main contactor 10 in Fig. 2 is closed.

In the case of three-stage control, the second stage torque is produced $t_n + T_{ms}$ after the point of time when the first stage torque was produced (for the third stage torque, the delay time may be only t_n).

In practice, the delay of the brake must be taken into consideration since it accounts for a substantial portion of the overall delay. However, no problem will occur if the release current is caused to flow earlier by as much as a period of time corresponding to the brake delay. In the case of speed reduction, there is no need to consider the brake delay. Fig. 22 shows an example of the notch interval setting for the embodiment of Figs. 11 and 12. The specification for the elevator is such that the rated speed is 60m/min, the rated load 600 Kg, the simple rod portion spring constant $K_s = 230$ kg/m, the minimum effective length of the ropes 5m, the maximum effective length of the ropes 20m, the number of ropes $n_1 = 4$, the spring constant of the rope K_1 , the weight of the cage 910 Kg, the Young's modulus of the rope $E = 6 \times 10^8$ Kg/cm², and the cross-sectional area of the rope $A = 53.4 \times 10^{-2}$ cm².

When the length of the ropes is $l = 20$ m, the overall spring constant of the rope K_1 becomes as follows:

$$K_1 = \frac{E \cdot A \cdot n_1}{l} = 640 \text{ Kg/cm.}$$

The overall spring constant of the simple rod portion spring K_2 is

$$K_2 = K_s n = 920 \text{ Kg/cm}$$

Thus, the combined spring constant K_{20} becomes as follows:

$$K_{20} = \frac{K_1 K_2}{K_1 + K_2} = 377 \text{ Kg/cm}$$

By similar calculation, the combined spring constant K_s becomes 677 when the effective length of the rope 1 is 5m.

Assume that the reduced mass m_1 of the motor portion is $m_1 = 14300$ Kg. Then the natural angular frequency ω can be obtained from the full cage mass $m_2 = 1510$ Kg (910 + 600) under the maximum load and 910 Kg under the minimum load in accordance with Equation (3) as follows:

$$\omega = \sqrt{K \cdot \frac{m_1 + m_2}{m_1 m_2} \times g}$$

g : acceleration due to gravity

Thus, the natural angular frequency and notch interval are as follows:

Under the maximum load;

$l = 2m$	$l = 5m$
$\omega_{20} = 16.4 \text{ rad/sec}$	$\omega_s = 22 \text{ rad/sec}$
$t_n = 0.191 \text{ sec}$	$t_n = 0.143 \text{ sec}$

Under the minimum load;

$l = 20m$	$l = 20m$
$\omega_{20} = 20.8 \text{ rad/sec}$	$\omega_s = 27.8 \text{ rad/sec}$
$t_n = 0.151 \text{ sec}$	$t_n = 0.113 \text{ sec}$

As will be seen from Fig. 22, under the minimum load, the optimum notch interval t_n varies in a range of 0.113–0.151 sec. depending upon the elevator position. Under the maximum load, the optimum notch interval varies in a range of 0.143–0.191 sec., and under an intermediate load, it varies in a range enclosed by the dotted line. Therefore, the correction of the notch interval in accordance with the effective length l of the rope and load weight may be carried out in the same manner as described above in connection with Figures 17 and 18. With an elevator constructed in accordance with foregoing specification, however, considerable vibration restraining effect can be produced without performing said correction. In this case, it is desirable that the notch interval t_n be set in a range of 0.143–0.151 sec. which is common to the respective conditions.

Fig. 23 is an oscillogram showing experimental results obtained in accordance with the present invention, wherein (a) indicates the case where the normal or rated torque was applied at the first stage without resorting to the present invention, and (b) represents the case where two-stage control was effected with the notch interval in accordance with the present invention. From this, it will be seen that remarkable vibration restraining

effect can be produced in accordance with the present invention. In the drawing, motor current is indicated instead of torque, and a torque curve can be obtained to be squaredly proportional to the value of the motor current where the slip of the motor is large.

WHAT WE CLAIM IS:—

1. An AC elevator controlling apparatus, comprising a traction sheave having a rope hung thereon, an elevator cage which is attached to said rope for upward and downward movement, at least one induction motor for driving said traction sheave, and control means for said induction motor or motors, wherein the control means is adapted to enable said induction motor or motors to produce at least two different magnitudes of torque in stages and at least either the magnitude or interval of at least one torque produced at and after the second stage is so selected as to restrain vibrations of the vertical vibration system of the elevator which have been caused by the torque produced in the previous stages.
2. An AC elevator controlling apparatus according to claim 1, in which cage position detecting means are provided for detecting the elevator cage position to thereby change the interval.
3. An AC elevator controlling apparatus according to claim 1 or 2, in which cage weight compensating means are provided for detecting the cage weight to thereby change the interval.
4. An AC elevator controlling apparatus according to claim 1, wherein the ratio of the magnitudes of torque produced by the induction motor is substantially 1:2, and the interval is set at substantially $1/2$ of the natural cyclic period of the vertical vibration system of the elevator.
5. An AC elevator controlling apparatus according to claim 1, wherein the ratio of the magnitudes of torque produced by the induction motor is 1:2:3:4 n, and the interval is set at $1/n$ of the natural cyclic period of the vertical vibration system of the elevator.
6. An AC elevator controlling apparatus according to claim 1, wherein when the ratio of the magnitudes of torque produced by

the induction motor is 1:2:3:..... n (n:even number), the interval t_n is set at $\frac{2n\beta}{\omega_{mean}}$

(β integer n; ω_{mean} :mean natural angular frequency).

7. An AC elevator controlling apparatus according to claim 1, wherein when the ratio of the magnitudes of torque produced by the induction motor is 1:2:3:..... n (n:odd number), the interval t_n is set at $\frac{\omega_{mean}}{2\pi\beta}$.

8. An AC elevator controlling apparatus according to claim 1, wherein at least two different magnitudes of torque in stages are changed in a stepped manner within the natural cyclic period of vibration of the vertical vibration system.

9. An AC elevator controlling apparatus according to claim 1, wherein the interval is set in a range common to the optimum interval range as the effective length of the rope varies under the minimum cage load and the optimum interval range as the effective length of the rope varies under the maximum cage load.

10. An AC elevator controlling apparatus according to any one of claims 1 to 9, wherein the drive motor is a squirrel-cage induction motor.

11. An AC elevator controlling apparatus as claimed in claim 1, arranged and operated substantially as described with reference to Figures 1 to 10 of the accompanying drawings.

12. An AC elevator controlling apparatus as claimed in claim 1, arranged and operated substantially as described with reference to Figures 11 to 16 of the accompanying drawings.

13. An AC elevator as claimed in any one of the preceding claims including a load detecting device substantially as described with reference to Figure 18 of the accompanying drawings.

J. A. KEMP & CO.,
Chartered Patent Agents,
14 South Square,
Gray's Inn,
London, W.C.1.

effect can be produced in accordance with the present invention. In the drawing, motor current is indicated instead of torque, and a torque curve can be obtained to be squaredly proportional to the value of the motor current where the slip of the motor is large.

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2. An AC elevator controlling apparatus according to claim 1, in which cage position detecting means are provided for detecting the elevator cage position to thereby change the interval.
3. An AC elevator controlling apparatus according to claim 1 or 2, in which cage weight compensating means are provided for detecting the cage weight to thereby change the interval.
4. An AC elevator controlling apparatus according to claim 1, wherein the ratio of the magnitudes of torque produced by the induction motor is substantially 1:2, and the interval is set at substantially $1/2$ of the natural cyclic period of the vertical vibration system of the elevator.
5. An AC elevator controlling apparatus according to claim 1, wherein the ratio of the magnitudes of torque produced by the induction motor is $1:2:3:4 \dots n$, and the interval is set at $1/n$ of the natural cyclic period of the vertical vibration system of the elevator.
6. An AC elevator controlling apparatus according to claim 1, wherein when the ratio of the magnitudes of torque produced by

the induction motor is $1:2:3 \dots n$ (n :even number), the interval t_n is set at $\frac{2n\beta}{\omega_{\text{mean}}}$

(β integer n ; ω_{mean} :mean natural angular frequency).

7. An AC elevator controlling apparatus according to claim 1, wherein when the ratio of the magnitudes of torque produced by the induction motor is $1:2:3 \dots n$ (n :odd number), the interval t_n is set at $\frac{2n\beta}{\omega_{\text{mean}}}$.

8. An AC elevator controlling apparatus according to claim 1, wherein at least two different magnitudes of torque in stages are changed in a stepped manner within the natural cyclic period of vibration of the vertical vibration system.

9. An AC elevator controlling apparatus according to claim 1, wherein the interval is set in a range common to the optimum interval range as the effective length of the rope varies under the minimum cage load and the optimum interval range as the effective length of the rope varies under the maximum cage load.

10. An AC elevator controlling apparatus according to any one of claims 1 to 9, wherein the drive motor is a squirrel-cage induction motor.

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13. An AC elevator as claimed in any one of the preceding claims including a load detecting device substantially as described with reference to Figure 18 of the accompanying drawings.

J. A. KEMP & CO.,
Chartered Patent Agents,
14 South Square,
Gray's Inn,
London, W.C.1.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1971.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

