NEW SPEED CONTROL TECHNIQUES FOR HIGH SPEED ELEVATORS

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ABSTRACT

The vertical vibration of elevator cars is a serious problem for some high speed elevator systems in tall buildings. To solve this problem an inverter controlled by 32 bits microcomputer has been developed. The system simulates the performance of ideal elevator model and computes the difference between computational speed of the ideal model and the real speed. According to the speed difference, the inverter controls the torque of the induction motor. This system is able to decrease the vertical vibration of elevateor car.

INTRODUCTION

Super-multistoried buildings is on the rise in Japanese cities as the harmony of the urban redevelopment programs and architectural technology improve. Today, new urban culture is made up of buildings ranging from 50-story high-risers to lower ones.

In the USA, 100-storied class buildings of 400 ~ 450m in height have been realized in overseas countries as represented by Sears Tower. The high-grade utilization of urban spaces is becoming an unavoidable trend of the times, and a 100-storied building era will certainly be realized in the near future in Japan. In preparing for such demand in the foreseeable future, we have been developing super high speed elevators having a stroke of 300 to 500m.

In this paper, the authors will introduce Hitachi's advanced technology in surpressing the vartical vibration.

1. TECHNICAL DEVELOPMENT PROBLEMS WITH THE ADVANCE OF HIGH SPEED AND LONG STROKE ELEVATORS

In order to develop super high speed elevators designed for super multistoried buildings, we have to solve several important problems as shown in Table 1.

	Technical problems	Developed technology
1	Large capacity power inverter control	Multi-inverter Low torque ripples
2	Vertical vibration suppression	Mechanical damper Model type vibration suppressing
3	Highly stable emergency stop device	Wear-resisting, high-friction sliding material
4	Large capacity hydraulic oil buffer	Long stroke plane
5	Horizontal vibration suppressing of cage	High vibration suppressing guide roller
6	Traveling noise suppression	Aerodynamic noise reduction structure Sound insulation structure

Table 1. Development problems of high speed elevators

One of these problems lies in the necessity of ensuring comfortable rides for the passengers, because the cage is apt to swing due to the use of very long ropes. As the rope becomes longer, the number of natural vibrations of the mechanical systems of elevator decreases, thus maintaining the stability of the cage difficult by conventional electrical control systems. The purpose of this study is to develop a new control system that suppresses mechanical system vibrations which may degrade the confort and also that ensures the stable speed regulation.

2. OCCURANCE OF VERTICAL VIBRATIONS OF THE CAGE AND REMEDIAL MEASURES

2.1 OCCURANCE OF VERTICAL VIBRATIONS OF THE CAGE

Fig. 1 shows the entire elevator system configuration. The electrical control system is constructed as a speed feedback regulating system that detects the motor shaft speed and enables the motor shaft speed to meet the speed command. On the other hand, the mechanical system is made up of the main rope coupling the cage, counterweight, sheave, and compensating rope tension sheave which results in the rope's spring and damper effect.

Since the rope becomes very long in super high speed elevators, the number of natural vibrations of the mechanical system consisting mainly of the rope, cage, and counterweight is low. When this number is close to the response frequency of the electrical control system, the control system becomes unstable. As a result, the cage vibrates at about 1~5Hz in the conventional method.

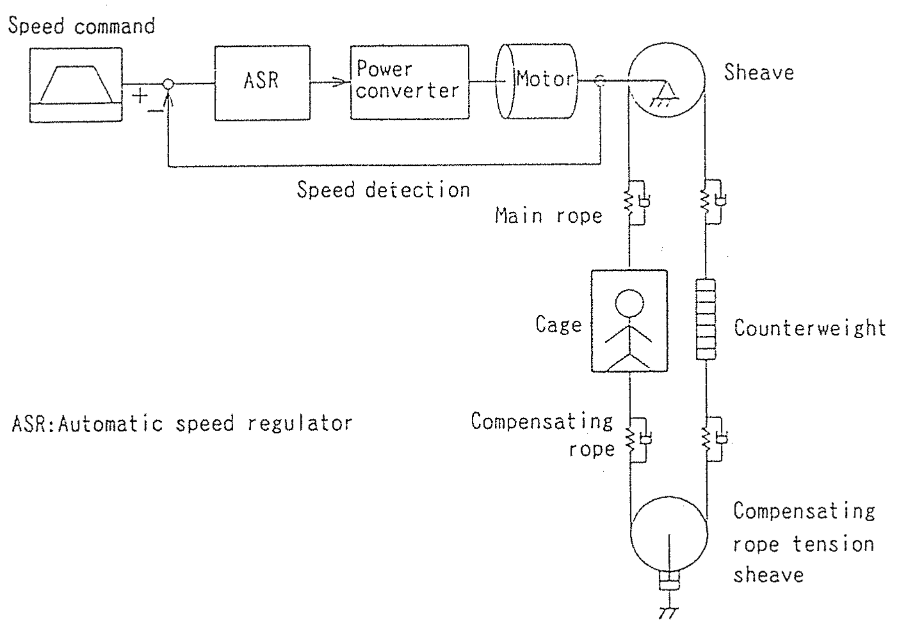


Fig.1 System Configuration

2.2 ROLES OF ELECTRICAL AND MECHANICAL VIBRATION SUPPRESSING SYSTEMS

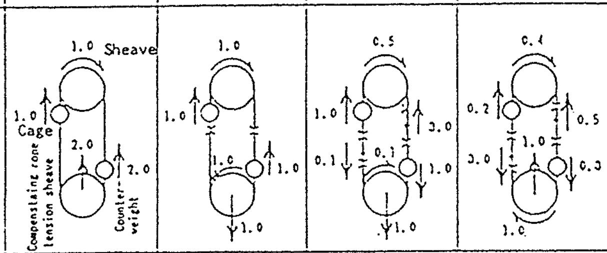
In addition to a change in the number of natural vibrations, the direction of the vibration (the cage and counterweight swing in the same direction or in the reverse direction.) also needs to be addressed. The authors equally divided the rope connections--sheave ~ cage ~ compensating rope tension sheave ~ counterweight ~ sheave--into five sections respectively, and calculated the vibrations by using a mechanical system model.

Fig. 2 represents the calculation results of the vibration modes. From this figure, it is understood that the number of natural vibrations change accord ing to the cage's position. Numerical values in each vibration mode show the intensity of relative vibrations of the cage, counterweight, and compensating rope tension sheave, and the number of revolutions of the sheave and compensating rope tension sheave for different cage positions. These results show that the vertical vibration of the cage, counterweight, and compensating rope tension sheave and the rotating directions/intensity of the sheave and compensating rope tension sheave change depending on the cage's position and the number of natural vibrations.

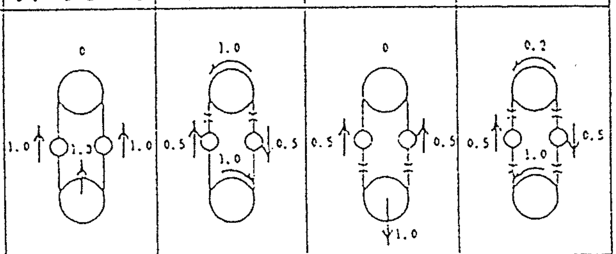
Accordingly, the authors eliminated these vibrations by means of the mechanical vibration suppressing device consisting of a compensating rope tension sheave damper and a counterweight damper and also electrical vibration suppressing device that uses an automatic speed regulator (ASR). The compensating rope tension sheave damper consists of two-gang alternating pulleys as a mechanical vibration suppressing device. A counterweight damper is also mounted as a vibration suppressing device for the counterweight.

Fig. 2 shows whether the vibration suppression is possible with the mechanical and electrical vibration suppressing devices or not for each vibration mode. In order to enhance the vibration suppressing effects, these vibration suppressing devices will be allocated for the following situations.

1. The electrical vibration suppressing device is applied mainly to a vibration mode where the cage conditions (vibrations) can be observed by the sheave ass'y with high sensitivity.
2. The damper of the compensating rope tension sheave is applied mainly to a vibration mode where the compensating rope tension sheave vibrates noticeably in the vertical direction.
3. A damper is mounted to the counterweight instead of the compensating rope tension sheave since the compensating rope tension sheave does not move up and down noticeably.

The number of vibration	1.01Hz	1.95Hz	3.63Hz	4.74Hz
Vibration mode				
Mecanical control	Effective	Effective	Effective	Somewhat Effective
Electric control	Effective	Effective	Somewhat Effective	Somewhat Effective

(1)Cage position:Top Floor

The number of vibration	1.05Hz	2.27Hz	2.96Hz	3.71Hz
Vibration mode				
Mecanical control	Effective	Effective	Effective	Somewhat Effective
Electric control	Ineffective	Effective	Ineffective	Somewhat Effective

(2)Cage position:Middle Floor

Fig. 2 Cage Position and The Number of Vibrations

3. ELECTRICAL VIBRATION SUPPRESSING METHOD

3.1 COMPARISON OF VARIOUS VIBRATION SUPPRESSING METHODS

Three kinds of vibration suppressing methods are available as shown in Fig. 3. The authors looked at these methods and compared their vibration suppressing effects, necessity of additional detectors, and simplicity of control(algorithm) during their application to elevators.

The conventional method, using a passive filter (T.T.F.:Twin T Filter), eliminates vibration components through the filter so as not to interfere with the automatic speed regulator (ASR) system. This method is characterized with an ease of control without requiring any additional detectors. Fig. 4 shows the step response of the ASR system (The cage is positioned at a middle floor.). From this figure, it is understood that the control system is diverged, when the ASR system response is set by a general design method. Vibrations can be suppressed if the ASR system response is low as shown by a solid line in Fig. 4. However, since the ASR system response cannot be lowered for the purpose of reducing the landing error of the cage, this method is not applicable for suppressing vibrations. This method is effective for conventional elevators having the resonance in a frequency range of 5Hz or higher, which does not interfere with the ASR system.

The next method is most effective of the three methods in suppressing vibration since it looks at the actual acceleration of the cage to produce vibration suppressing signals. However, this method requires the control unit to constantly recalculate the rope system constants that noticeably change depending on the cage's positions. As a result, the algorithm becomes complicated. Since detectors are mounted on the long distance between the controller and the cage results in more, unwanted electrical surge interfering more with the signals, and the troubleshooting of these detectors is difficult. This method is most suitable for systems requiring high-grade control.

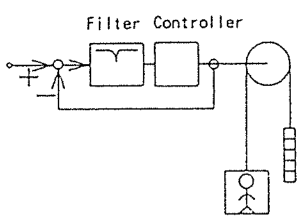
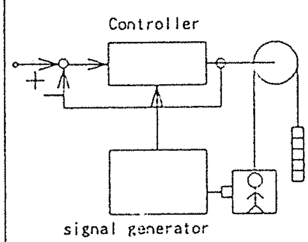
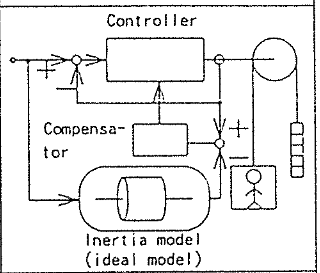
Method	Adjusting of the filter constant (The conventional method)	Detecting the acc-eletion of the cage	Estimating the vib-ration of the cage (The new method)
Configuration			
Vibration suppressing effect	Ineffective (for super high speed erevetor)	Effective	Effective
Additional Detectors	Unnecessary	Necessary	Unnecessary
Algorism	Simple	Complicate	Rather complicate

Fig.3 Comparison of Various Vibration Suppressing methods

The third method caluclates the vibration components of the cage by considering both the actual speed of sheave shaft and the expected speed of the shaft in the memory to produce vibration suppressing signals. This expected speed is that of an ideal model and obtained by working out the inertia of the sheave ass'y from the mechanical system. Since the model remains unchanged in this method, the algorithm is simple and no detectors are necessary for the cage. Accordingly, steady control is obtainable with the simple algorithm as compared to two methods described above.

Judging from these comparison results, the authors adopted the third system where we estimate the vibration components for super high speed elevators, and deferred the second method of detecting the vibration of the cage as a future system. Now, the authors will examine the vibration suppressing effects of this vibration components estimating system.

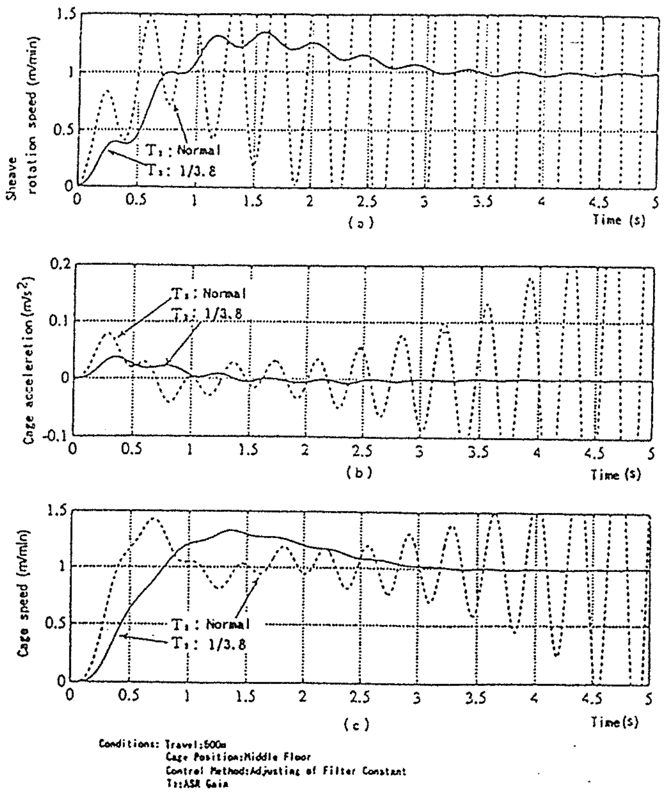


Fig. 4 Step Response of Cage Speed in the Conventional Control Method

3.2 CONTROL SYSTEM CONFIGURATION

Fig. 5 shows the block diagram of the vibration suppressing system (hereafter referred to as the model type vibration suppressing method) discussed in paragraph 3.1. This control system consists of a conventional loop, where the sheave speed is controlled by the speed feedback regulating system and the speed command, and a vibration suppressing loop. The latter is a model type configuration loop. The model is composed of an ASR system that sends out commands baased on the ideal condition without vibration components. This ASR system, only one material point exists at the sheave shaft, and the entire mechanical system of the elevator is caluculated as the inertia of the sheave shaft.

This system estimates the predictive speed of the motor shaft excluding the vibration components, and then, estimates vibration components as the difference between the actual speed detected, containing the vibrations, and the predictive speed. This system inputs the results into the compensator and calculates the vibration suppressing signal, or, the torque command signal to suppress vibrations.

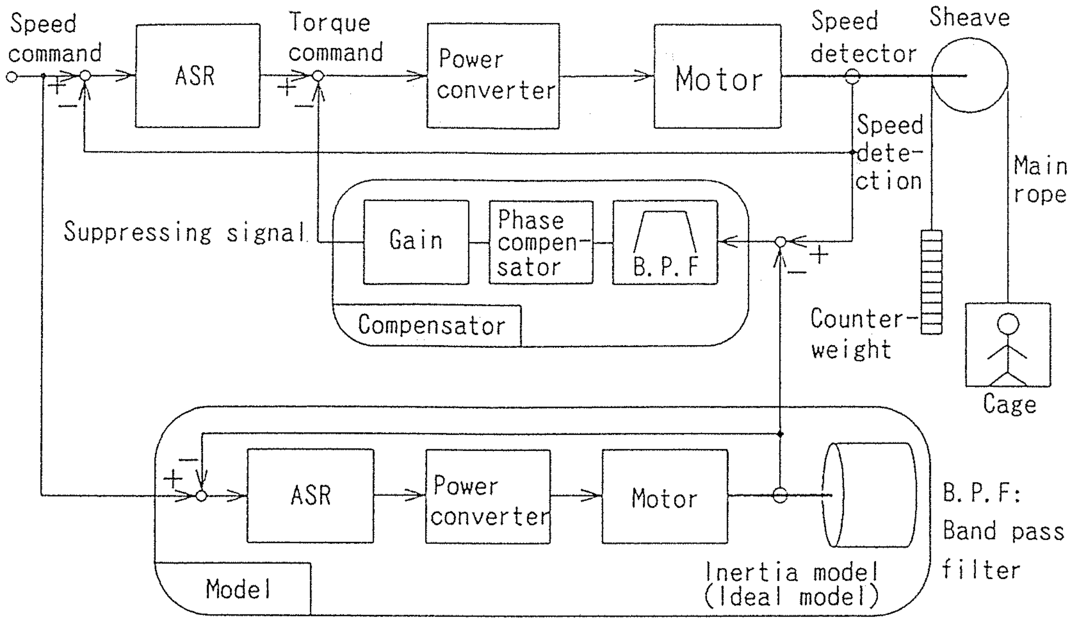


Fig.5 Block Diagram of The New Control Method

3.3 SYSTEM CONFIGURATION OF INVERTER ELEVATOR

Fig. 6 shows the system configuration of a super high speed inverter elevator adopting the new control system. A high speed elevator is designed to transmit the motor torque to the sheave via a high-efficiency reduction gear, while this new super high speed elevator is designed to run on a motor direct coupling drive system, or a gearless hoist system.

It also employs an inverter parallel drive system where two inverter units are combined with independent two-winding tandem motors. When a phase difference exists in the currents flowing in the two windings of the motors, the torque ripples caused by a current waveform distortion of inverters are reduced to a half because of the diverged generation timing. This new elevator also uses sinusoidal input/output current type inverter units which have been employed for conventional high speed elevators.[1]

The vibration suppressing control system is arithmetically operated by a subordinate microcomputer, and the results (the current, frequency, and phase commands) are sent to the PWM control circuit of the inverters. Having a need for high speed control calculations, a 32 bits microcomputer with a coprocessor is newly instituted to serve as a subordinate microcomputer.

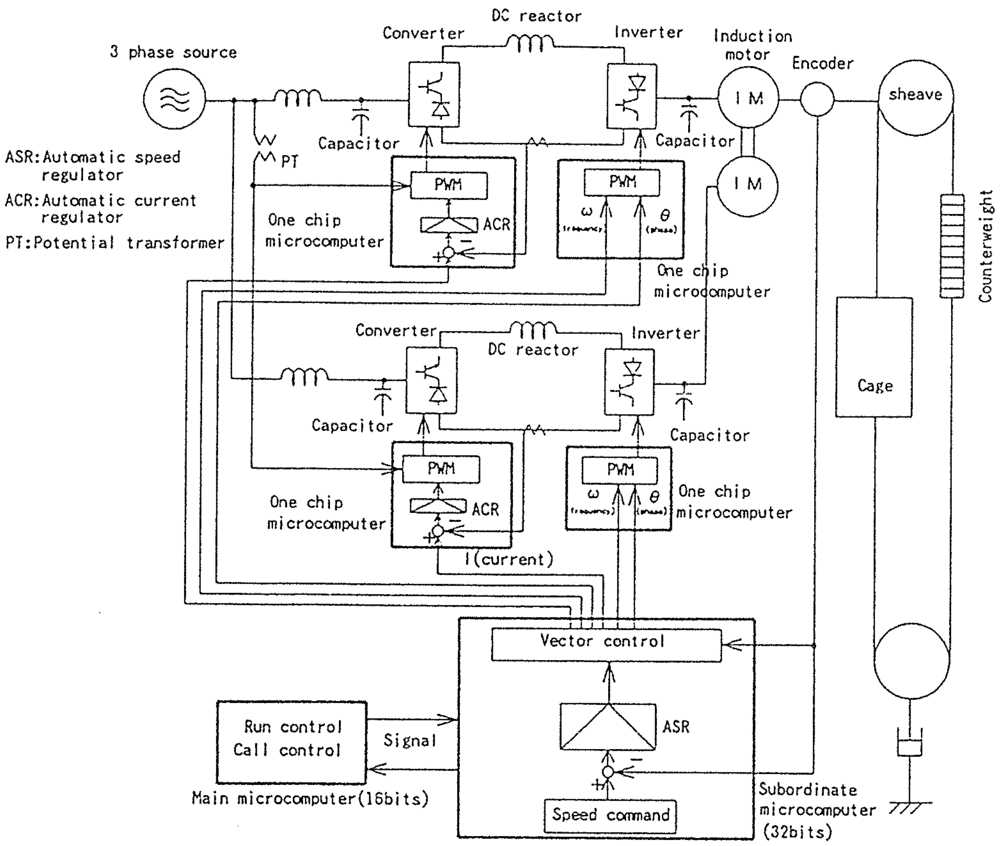


Fig. 6 System Configuration of Current Inverter Elevater

4. EFFECTS OF NEW CONTROL SYSTEM

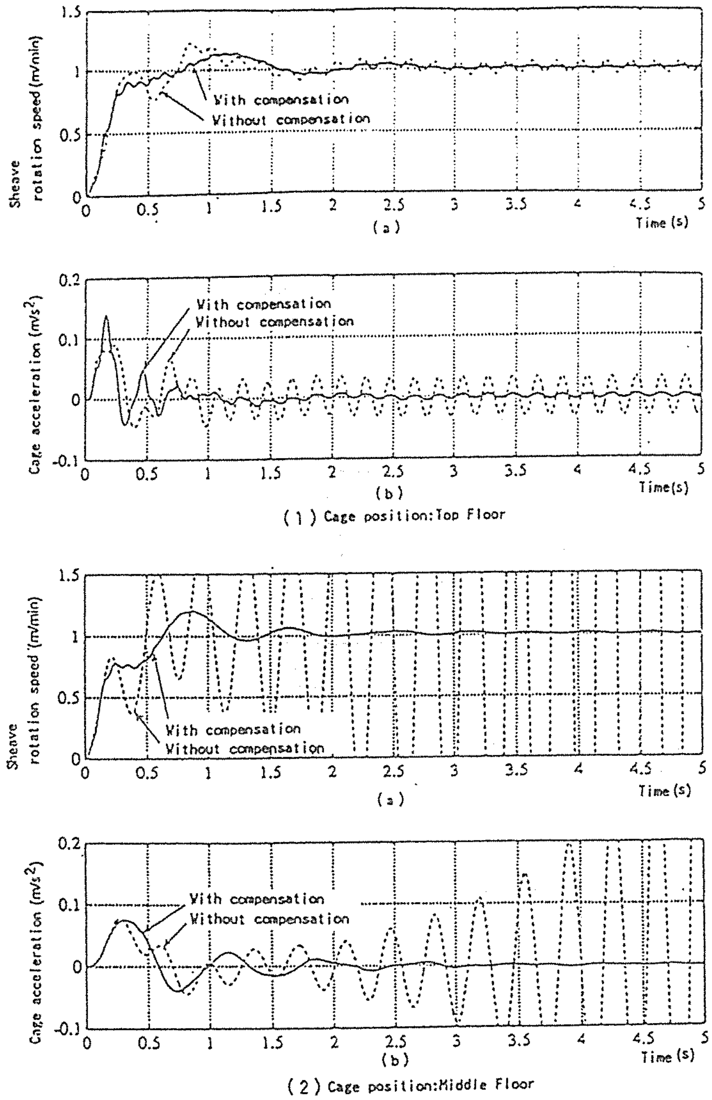
4.1 SIMULATION RESULTS

The authors carried out the simulation to see the responses of the sheave speed and cage acceleration to the step input of speed command. Motor torque ripples were applied by a sinusoidal current as a disturbance whose peak value (=45Nm) is 0.5% of the motor rated torque. The disturbance frequency is specified to be 5.3Hz (on a top floor) or 2Hz (on a middle floor).

Fig. 7 shows the simulation results. When the model type vibration suppressing method offered in this paper is applied, as shown by "with compensation" and a solid line in the figure, the vibration of the cage was reduced from $\pm$ 0.05m/s^2 to $\pm$ 0.0035m/s^2 at the top floor, or reduced by about 90% as compared to the control system "without compensation" and indicated by a dotted line.

In a middle floor, the cage vibration is diverged in the conventional system. When the model type vibration suppressing method is applied, the sheave speed and cage acceleration response are stabilized, and cage vibration is suppressed to be within $\pm$ 0.1m/s^2.

From these simulation results, we can judge that cage vibration is suppressed by applying the model type vibration suppressing method.



Conditions: Results of simulation
Travel:500m
Control Method:Estimating of cage vibration

Fig. 7 Step Response of Cage Acceleration in the New Control Method

4.2 EXPERIMENTAL RESULTS BY A GROUND TESTING SYSTEM

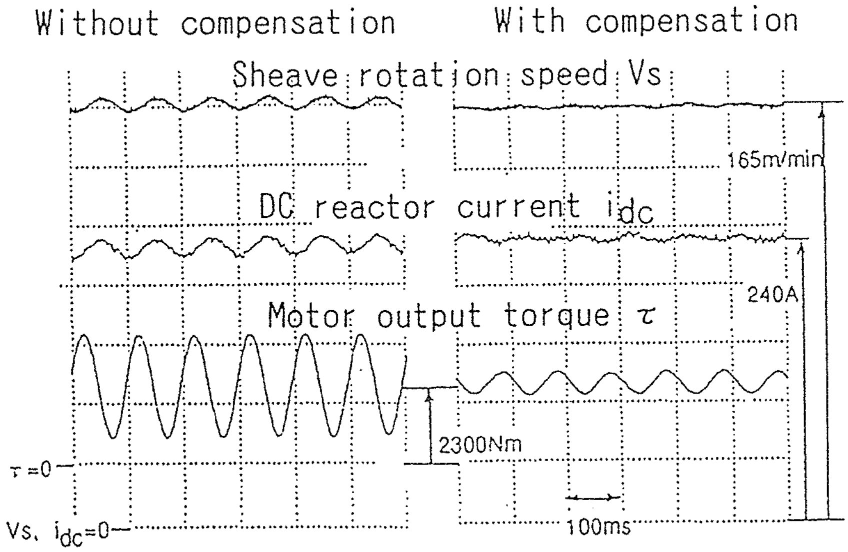
Regarding the simulation results in the last paragraph, the effects of the model type vibration suppressing system were confirmed by an experiment using a ground testing system that simulates an actual motor torque.

Since this ground testing system model concentrates all inertia of an entire elevator to the sheave shaft, the vibration mode differs from that of an actual elevator, and also the vibrations at the resonance point can be suppressed by the conventional twin T filter. Neither can this testing system verify the original vibration suppressing effects of the new control method.

Thus, to get a clear picture of the vibration suppressing effects, experiments were conducted by applying a disturbance having the same frequency as the resonance point frequency (10Hz) after removing the conventional filter.

By applying a 10Hz disturbance to the current command during steady-state traveling in conventional control system--without using any vibration suppressing signal--the motor shaft torque ripples are about ±1500Nm. When the model type vibration suppressing control is used under the same condition, the motor shaft torque ripples are reduced to about ±330Nm, or reduced by about 78%. Fig. 8 shows these experimental results.

Now, the operation and vibration suppressing effects of the model type vibration suppressing control were verified.



Conditions (Experimental results by a ground testing system; Control method : Model type vibration suppressing method)

Fig. 8 Control Characteristics of Inverter Elevator

5. CONCLUSIONS

In this paper, of the research problems the authors faced in realizing super high speed elevators, the authors examined a new method of electrically controlled system to suppress the vertical vibration of the cage that are resulted from the resonance of the natural vibrations of the mechanical system, whose number of vibration was shown to lower as the elevator strokes become longer. In multistoried buildings, the number of mechanical natural vibrations of the rope cage system lowers to cause a resonance to be produced with the response frequency of the ASR system. Accordingly, it is difficult to construct a stable control system by the conventional method having a passive filter in the ASR loop.

The authors estimated the vibration components of the cage as the difference between the actual speed and the estimated speed where the latter was obtained by using an ideal vibration-free model. This vibration components are then interpreted by a model type vibration suppressing system together with the electrical control system as the cage vibration needing adjustment. The control systems will then make appropriate adjustments to stabilize the elevator.

REFERENCES

(1)H. Inaba et al.,"High-speed Elevators Controlled by Current Source Inverter System with Sinusoidal Input and Output," Elevator World, 54-59, March(1989).