# Active Roller Guide System for High-speed Elevators

**Kenji Utsunomiya, Ken-Ichi Okamoto, Takashi Yumura,**

**Kiyoshi Funai and Hisao Kuraoka**

***Mitsubishi Electric Corporation, Japan***

**Key Words:** Active control, lateral vibration, roller guide, simulator

## ABSTRACT

Mitsubishi Electric has developed an active roller guide system to suppress the lateral vibration of high-speed elevators. Lateral vibration is mainly caused by guide rail deformation and guide rail alignment error. Development of the system required that we first actually measure the guide rail displacement in several hoist ways and introduce a new simulator capable of enabling us to design the optimal active vibration isolation system. Next, we used the simulator and rail displacement data to design an active roller guide system that suppresses the lateral vibration of elevator cars. We manufactured an active roller guide and conducted experiments with actual elevators in experimental towers. Experimental results show that the active roller guide system is capable of reducing the lateral vibration of elevator cars to nearly half.

## 1. INTRODUCTION

Elevator lateral vibration is one of the main problems affecting ride comfort in high-speed elevators. Such lateral vibrations are mainly caused by guide rail deformation and guide rail alignment error. Therefore the procedure for providing ride comfort has been to ensure that guide rails are machined precisely straight and installed correctly in the hoist way. However, a special installation technique is required to do so. Several active vibration control systems have been studied, and new methods to suppress lateral vibration without using special techniques have been reported. For example, the method of using an AC servomotor and ball screw installed between the car and frame [1], the method of using an active mass damper[2], and the method of using electromagnets installed on the frame [3]. However, there seems to be no report describing the design of an optimal active vibration isolation system taking account guide rail irregularities. Therefore, we utilized simulation analysis and actual guide rail displacement data to develop an active vibration isolation system that suppresses elevator lateral vibration and can be applied to a wide variety of high-speed elevators.

In this paper, we first discuss the simulator we developed to determine elevator lateral vibration during the process of designing vibration isolation systems. We describe the analysis of the rail disturbance spectrum and elevator vibration mode in order to find the main cause of lateral vibration and contemplate methods to suppress such vibration efficiently. We then discuss the basic structure and features of the active roller guide system and the optimal design using this simulator. Finally, we describe experiments conducted using actual elevators in experimental towers to check the performance of the system.

## 2. VIBRATION ANALYSIS

### 2.1 Simulator for elevator lateral vibration

We developed a new simulator for elevator lateral vibration to support the design of an

active roller guide system. [4] The special features of this simulator are as follows.
(1) It enables quantitative analysis of the lateral vibration of elevator cars taking into account the disturbance resulting from actual rail irregularities.
(2) It can reproduce three-dimensional dynamic behavior, and gives simulation results that agree extremely well with actual measurement results.

***Figure 1*** shows an outline of the simulation model, and ***Figure 2*** a comparison of simulation and measurement results of car vibration time response. The latter figure shows that the simulation results agree extremely well with the actual measurement results. The simulator has been verified to have extremely high precision via comparison to actual measurements taken at various buildings.

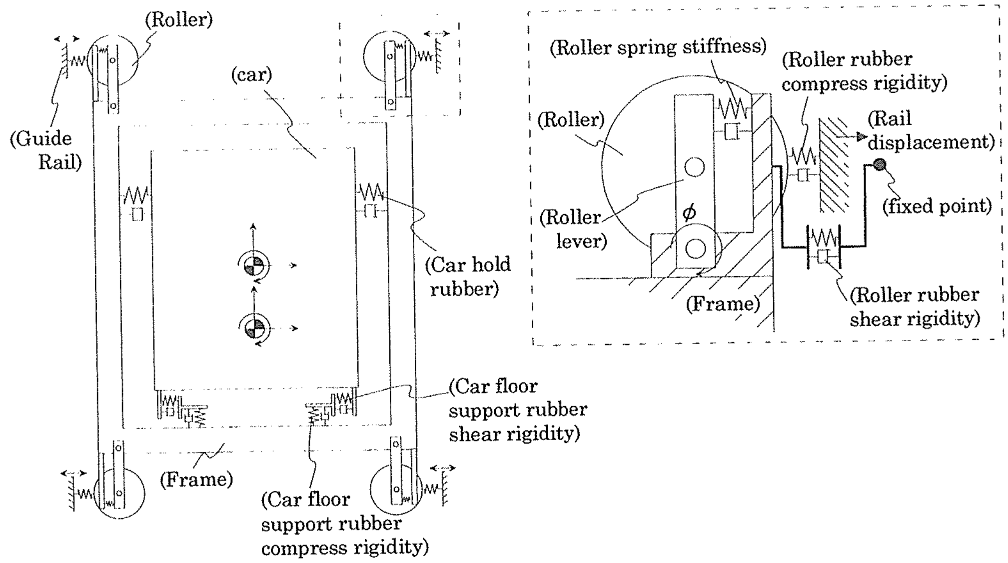



*Figure 1. Dynamic Model of Lateral Vibration Simulation*

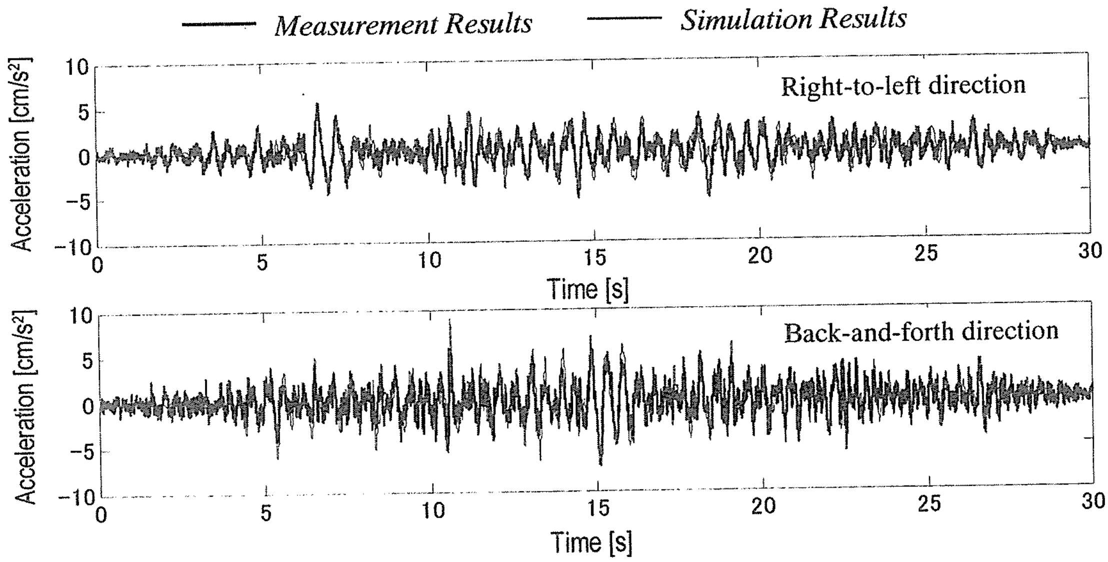



*Figure 2. Simulation Results of Floor Lateral Vibration*

## 2.2 Vibration mode and rail displacements

Guide rail irregularities excite many elevator vibration modes, and some of the modes are easily excited. In this section, we discuss the structure of active vibration control suitable for high-speed elevators by analyzing the vibration mode and rail displacements using the simulator we developed. ***Figure 3*** shows the power spectrum density of a certain guide rail displacement when an elevator is traveling at a speed of 420m/min. It shows that the disturbance caused by rail irregularities has a frequency spectrum that depends on the traveling speed and length of the rail. In this case, the traveling speed is 420m/min and the length of the rail is 4m. Accordingly, the exciting frequency is calculated in *Eq. (1)*. This special characteristic is shown in many actual guide rail displacement data.

$$(420/60)/4 = 1.75 \text{ [Hz]} \quad \ldots(1)$$

The length of rails used is generally 4 or 5m. Accordingly, the main frequency of rail disturbance is 0.8 to 2.5Hz if we assume that the traveling speed of high-speed elevators to be in the range of 240-600m/min.

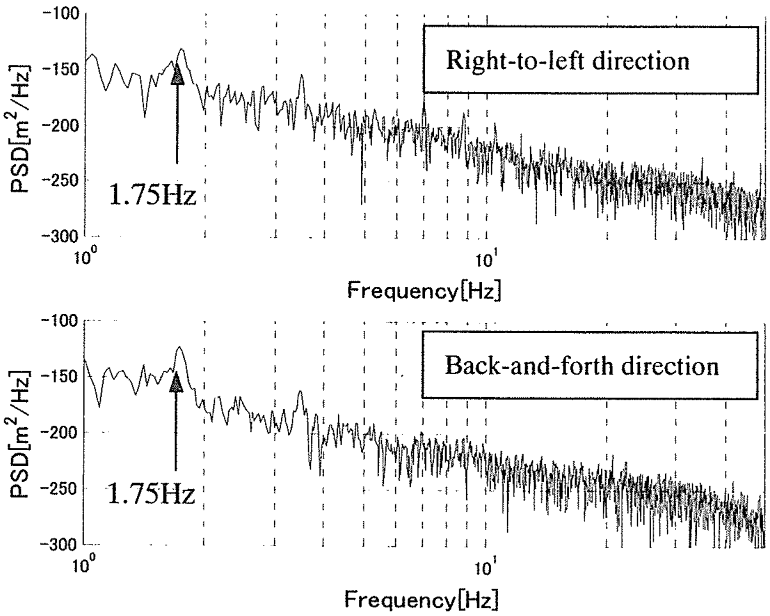



***Figure 3. Power Spectrum Density of Rail Displacement (Traveling Speed: 420m/min)***

***Figure 4*** shows the main modal shape of a certain high-speed elevator derived from the new simulator. It shows that the vibration modes near the main rail disturbance frequency (0.8-2.5Hz) are the modes where the car oscillates in phase with the frame. This special characteristic is common in the general high-speed elevators of our company.

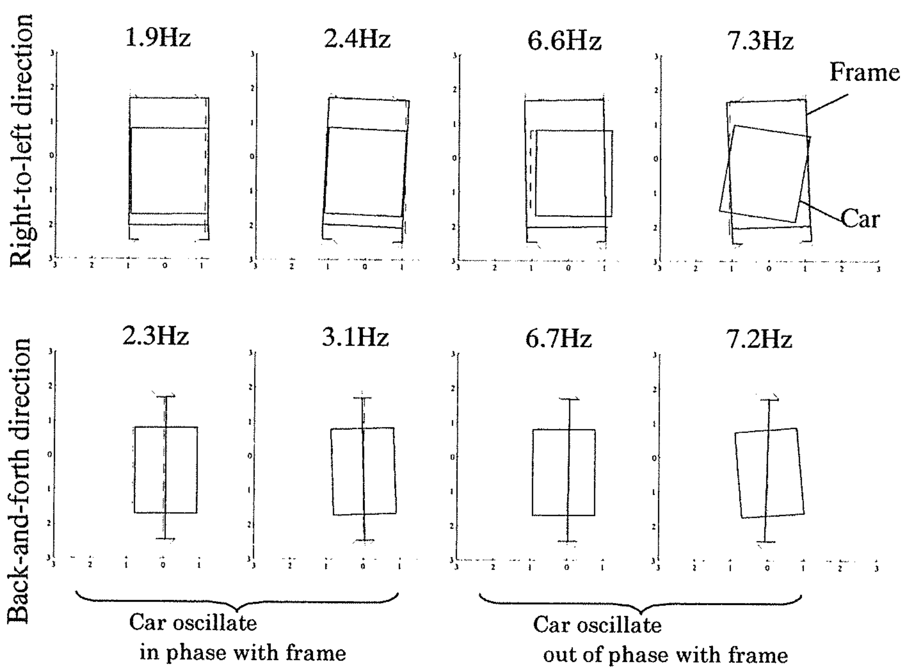



***Figure 4. Main Modal Shape of High-speed Elevator***

Accordingly, the attachment of actuators to the guide system is effective for suppressing the lateral vibration excited by the actual rail displacements because this method suppresses such modes efficiently.

## 3. ACTIVE ROLLER GUIDE SYSTEM

### 3.1 Basic structure of active roller guide system

***Figure 5*** shows the structure of our active roller guide system. The system is composed of two active roller guides attached to the bottom of the frame and control units on the top of the frame. Only the two roller guides attached to the bottom of the frame are actively controlled in order to minimize cost. This structure was chosen taking into account the fact that the bottom of the frame is near both the car's center of gravity and car floor.

Next, we explain the basic process for suppressing lateral vibration. The vibration of the elevator is detected by accelerometers at the bottom of the frame. The signal of acceleration is integrated to determine the frame velocity and the control force signal is determined based on the velocity in the controller. An amplifier drives the actuators according to the control force signal. More simply stated, the active roller guide system applies sky-hook damper technology. [5] The technique is able to suppress the vibration mode frequency peak without harming high-frequency response.

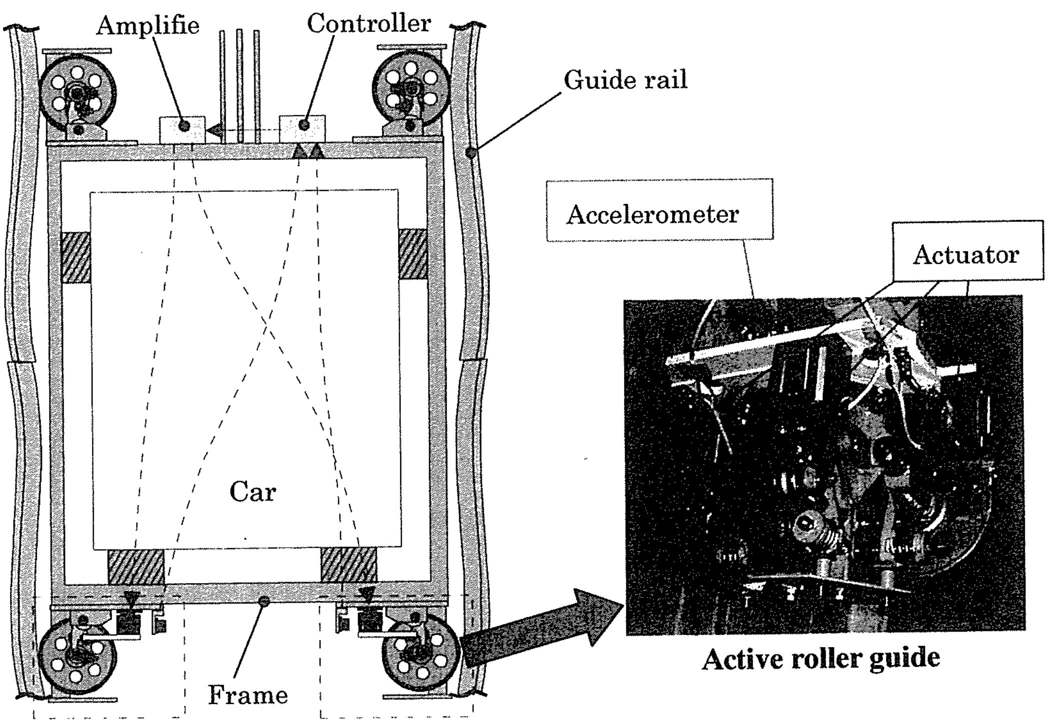



*Figure 5. The Structure of Active Roller Guide System*

### 3.2 Special features of the active roller guide system

**(a) Noise canceling filter**

Our active roller guide system utilizes accelerometers to detect elevator vibration, as shown in ***Figure 5***. We incorporated an inexpensive capacitive silicon micro-accelerometer originally developed for automobile control in order to maintain cost efficiency. Although it has high sensitivity compared to common silicon accelerometers, there is larger amount of noise output as compared to more expensive, high-grade accelerometers. Such noise causes various problems in active control systems. Especially, when an acceleration signal is integrated as in this system, low frequency noises are amplified by the integrating operation, and problems such as those listed below can occur.

(1) Even if an elevator is stopped at a floor and is not oscillating, the actuators are operate due to the noise, thus causing the elevator car to oscillate and making the passengers feel uncomfortable.

(2) Electricity consumption increases because amplifiers supply power to the actuators even when the elevator is stopped at a floor.

In order to solve such problems, we developed an original digital-filtering algorithm, as shown in ***Figure 6***. This filter acts as shown in ***Figure 6-b*** and *Eq. (2)*.

$$f(x)=\begin{cases} x, & if\ abs(x)\geq a \\ 0, & if\ abs(x)<a \end{cases} \qquad where\ \ a\ldots constant\ depend\ on\ noise\ quantity \qquad \ldots(2)$$

Without this filter, the integrated signal causes large vibration even when an elevator is stopping. On the other hand, after filtering, the integrated signal settles to zero whenever the elevator is stopping. When the elevator is traveling, the signal is almost same as when no filter is used because the filter eliminates only the small acceleration signal. (cf. ***Figure 6-c***)

***Figure 6*** shows that this original filtering algorithm solves the above-mentioned problems.

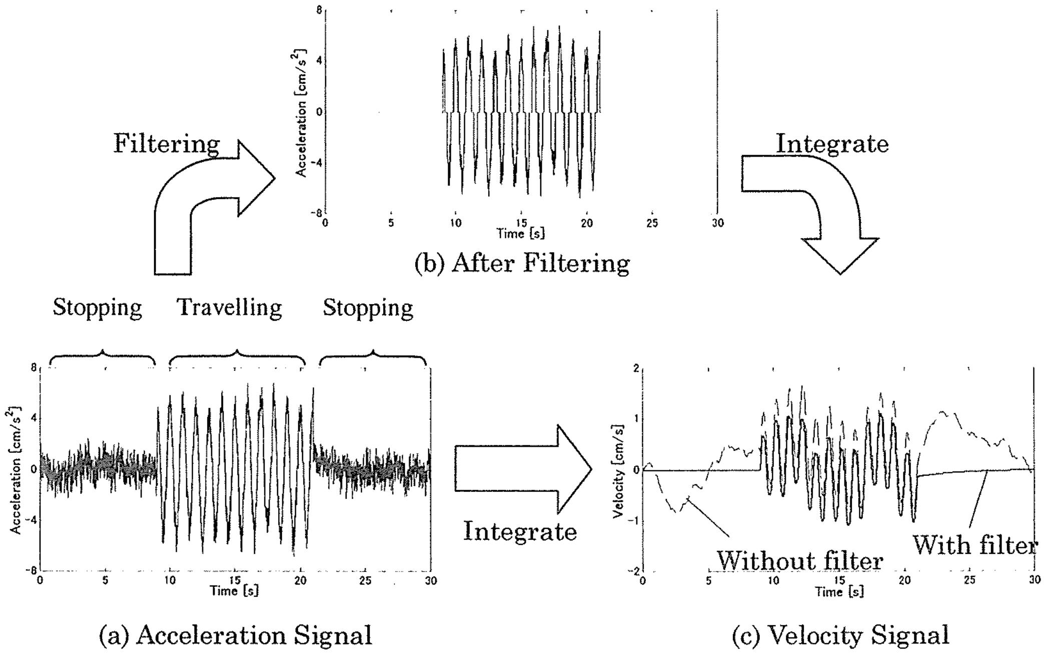



***Figure 6. Effect of Noise Cancel Filter***

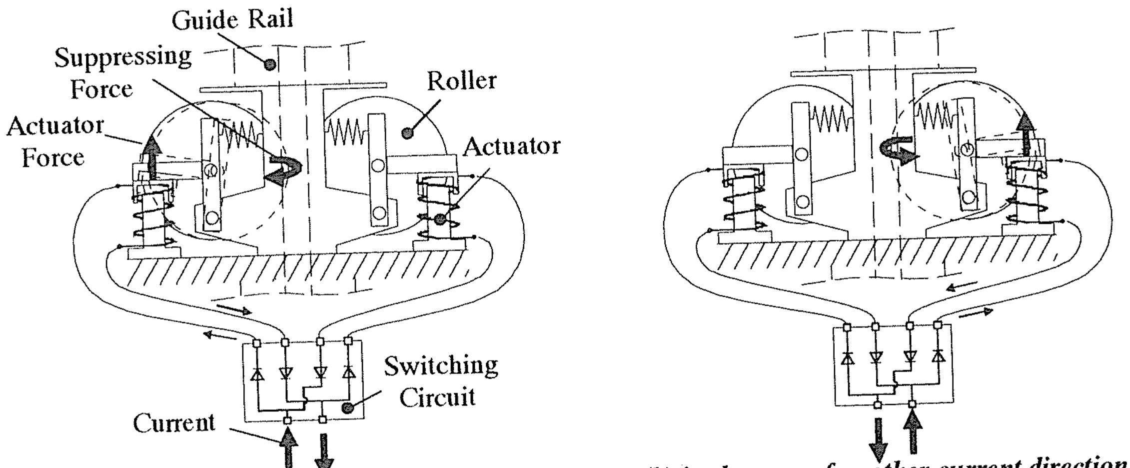
**(b) Switching drive for dual actuators**

We have introduced a method in which the amplifier drives two actuators attached to the front and rear rollers via a switching circuit in order to minimize cost. ***Figure 7*** shows the behavior of the switching drive apparatus.

**(c) Optimum design of actuator performance**

We have designed a control system that suppresses lateral vibration up to as much as half over a wide velocity range by calculating time response utilizing the simulator and actual rail displacement data. We also estimated the required performance of the actuators (e.g., power, stroke) during simulations. We then applied the minimum required performance to actuators in order to reduce their weight, bulk and cost.

***Figure 8*** shows the estimated performance with an active roller guide system that equipped with the control system and actuators designed as stated above. It shows that this system is capable of suppressing lateral vibration of general high-speed elevators up to as much as half over a wide velocity range.




*(a) in the case of a current direction* *(b) in the case of another current direction*

***Figure 7. Behavior of Dual Actuator Switching Drive***

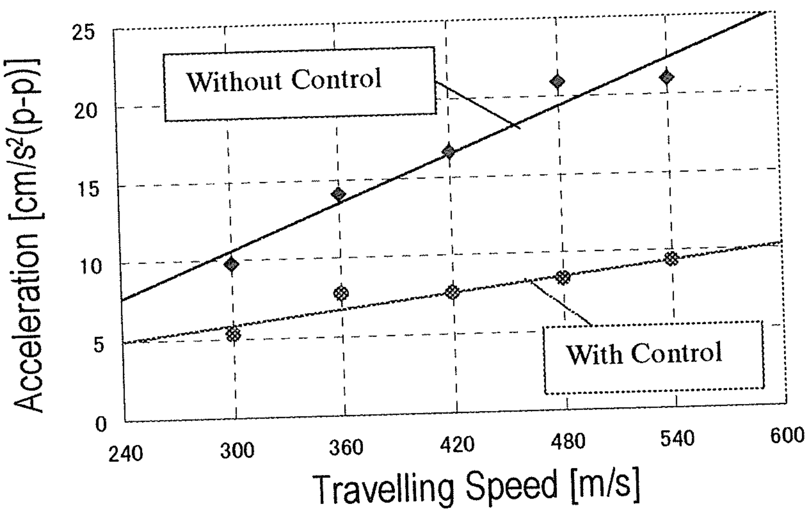



***Figure 8. Performance of Active Roller Guide System Estimated with Simulator***

## 4. EXPERIMENTAL RESULTS

To check the performance of our active roller guide system, we conducted experiments using two actual elevators (i.e., speeds of 300 and 420m/min) installed in experimental towers. The experimental and simulation results for the traveling speed of 300m/min are shown in ***Figure 9***. From this, the following two important facts were obtained.

(1) It was proven that our active roller guide is capable of suppressing elevator car lateral vibration to almost half of that measured when the car is operated without control: Right-to-left direction, from 14 to 6cm/s$^2$; Back-and-forth direction, from 12 to 7cm/s$^2$).

(2) The simulation results agree extremely well with experimental results not only in the case without control but also in the case with control. Accordingly, performance estimates by the simulator have been verified to be quite reliable.

***Figure 10*** shows the experimental results for the traveling speed of 420m/min. In this case, we intentionally increased the lateral vibrationby causing an imbalance in thecar load. Our active roller guide was able to suppress the lateral vibration from a large23cm/s$^2$ to 9cm/s$^2$. Furthermore, total power required was only 70.4W, and the average total power was no more than 6.1W throughout the experiment. This result shows that our active roller guide system realizes high performance and low electricity consumption.

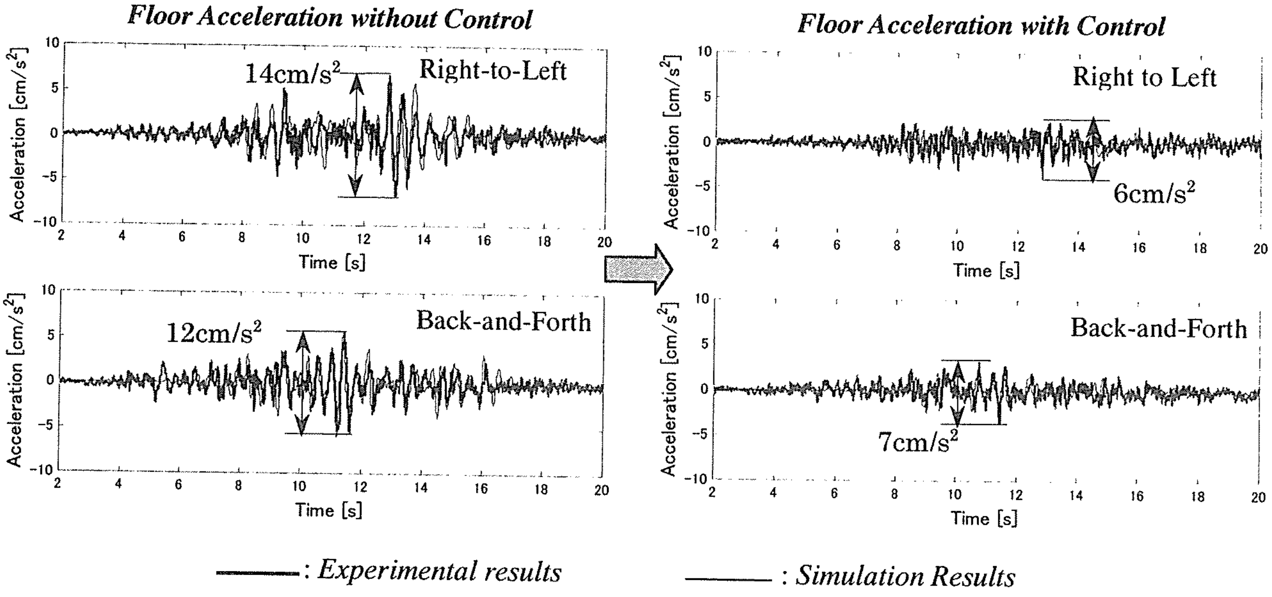



*Figure 9. Performance of Active Roller Guide System Using Actual Elevator (Traveling Speed: 300m/min, Capacity: 1600kg)*

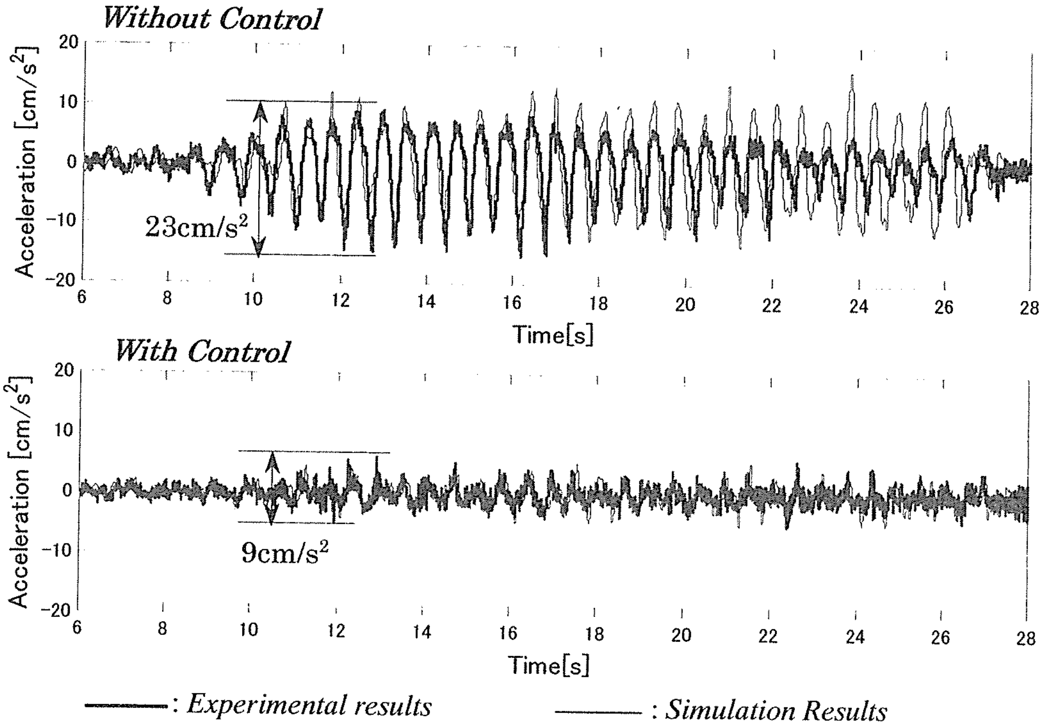



*Figure 10. Performance of Active Roller Guide System Using Actual Elevator (Traveling Speed: 420m/min, Capacity: 1600kg)*

## 5. CONCLUSIONS

We have developed an active roller guide system that is capable of suppressing the lateral vibration of elevator cars by up to as much as 50%. The features of the system are as follows.

(1) The development of an original filtering algorithm enables the use of inexpensive accelerometers in the system. As a result, we have succeeded to reducing system cost.

(2) Consumption of electricity has been minimized.
(3) Easily applicable to existing elevators owing to the small, lightweight system design.

This system was designed using a new lateral vibration simulator that is extremely precise, thus resulting in a reduction in the time required to develop it. Experimental results were nearly identical to expected performance.

System performance was checked by conducting experiments using several actual elevator installation. Plans are to continue development of the system with the objective of practical application in the market.

## REFERENCES


[1] Yamazaki, Y., M. Tomisawa, et al. (1994) *Vibration Control of Super-High-Speed Elevators*. JSME, No.60-579, pp190-195 (in Japanese).

[2] Teshima, N., K. Kamimura, et al. (1996) *Vibration Control of an Ultra high Speed Elevator by Active Mass Damper*. The 5th Transportation and Logistics Conference, Dec. 1996, JSME, pp97-100 (in Japanese).

[3] Mutoh, N., K. Kagomiya, et al. (1998) *Horizontal Vibration Suppression Method Suitable for Super-High-Speed Elevators*. T. IEE Japan, Vol.118-D, No.3, pp353-362 (in Japanese).

[4] Utsunomiya, K. and T. Yumura,.(2000) *Development of Simulator for Elevator Lateral Vibration*. The 9th Transportation and Logistics Conference, Dec. 2000, JSME, pp107-108 (in Japanese).

[5] Karnopp, D. (1981) Vehicle System Dynamics.


## BIOGRAPHICAL DETAILS


**Kenji Utsunomiya** joined Mitsubishi Electric Corporation in 1997. He is presently a mechanical engineer in the Intelligent Building & Transportation Systems Department, Industrial Electronics & Systems Laboratory, Mitsubishi Electric Corporation, Japan.

**Ken-Ichi Okamoto** joined Mitsubishi Electric Corporation in 1989. He is presently a mechanical engineer in the Intelligent Building & Transportation Systems Department, Industrial Electronics & Systems Laboratory, Mitsubishi Electric Corporation, Japan.

**Takashi Yumura** joined Mitsubishi Electric Corporation in 1983. He is presently group manager of the Intelligent Building & Transportation Systems Department, Industrial Electronics & Systems Laboratory, Mitsubishi Electric Corporation, Japan.

**Kiyoshi Funai** joined Mitsubishi Electric Corporation in 1979. He is presently manager of the Elevator Mechanical Development Section, Inazawa Works, Mitsubishi Electric Corporation, Japan.

**Hisao Kuraoka** joined Mitsubishi Electric Corporation in 1995. He is presently an engineer in the Elevator Mechanical Development Section, Inazawa Works, Mitsubishi Electric Corporation, Japan.