A New Slide Guide Shoe to Suppress Elevator Vibration

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ABSTRACT

We have developed a new slide guide shoe to decrease the lateral car vibration of an elevator. The key features of this novel slide guide shoe are its support structure and the specific shoe shape. We first present a simulation model for evaluating lateral elevator vibrations caused by the force generated at the guide shoes. Next, we apply the simulation results to the design of the guide's structural parameters to decrease elevator vibration.

Simulation and experimental results show that the slide guide shoes are effective in suppressing lateral car vibration of an elevator.

1. INTRODUCTION

Recently, there have been increasing expectations for elevators to have high speed and lightweight characteristics. However, the exciting force generated at the guide shoes is increases with elevator speed. Furthermore, passenger cage vibration tends to increase with a reduction in elevator weight. Therefore, we developed a new slide guide shoe that has an improved capability to suppress elevator vibration caused by the exciting force generated at the guide shoes. The key features of this novel slide guide shoe are its support structure and the specific shoe shape.

First, we discuss a simulation model of elevator dynamics to evaluate elevator vibration caused by the force generated at the guide shoes. The simulation results revealed a guide rail displacement pattern that has the greatest influence to elevator vibration.

We designed the specifications of a support structure and a specific shoe shape to diminish the exciting force caused by the observed guide rail displacement pattern. These structural parameters were optimized by simulation studies.

The effectiveness of the developed slide guide shoe in suppressing the vibration generated by rail displacement is demonstrated by experimental results.

2. SIMULATION MODEL

To estimate the lateral vibration cased by guide rail displacement, we derived a simulation model of elevator dynamics. As shown in *Fig. 1*, a passenger cage is dynamically contacted by rubber pad to the elevator car frame. The car frame is installed in the building so that vertical movement is enabled along the guide rails in the elevator path. The movement of the guide shoe is restricted by the guide rail. Consequently, the exciting force generated by the rail displacement of the guide rails causes vibration of the frame and passenger cage.

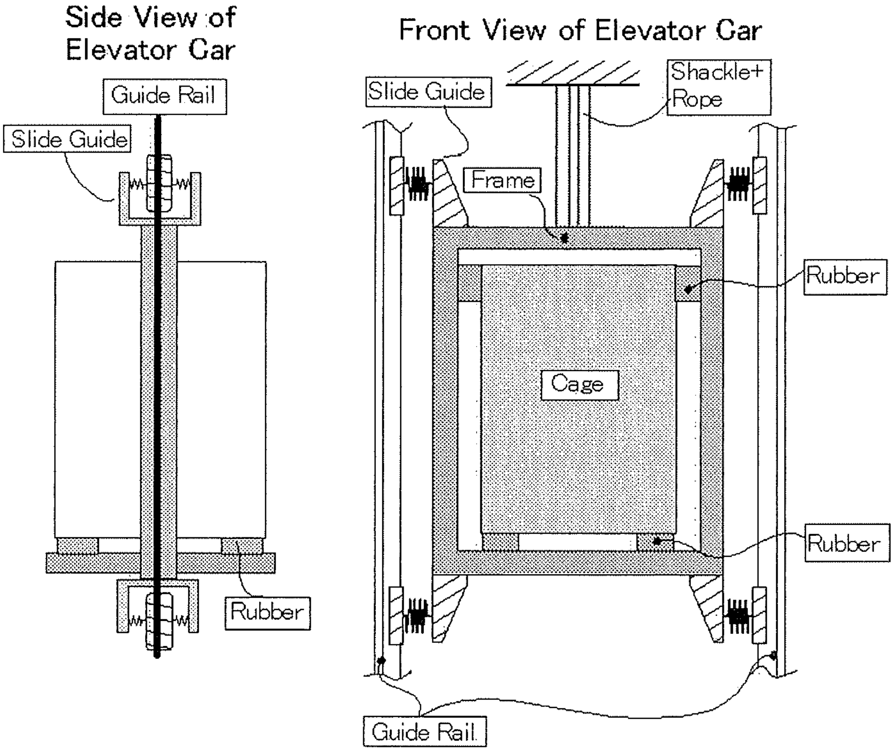


Figure 1. Dynamic Model of Elevator Structure

To describe the equation of elevator vibrations caused by the guide rail displacement, we first derive the equation of motion with no restraint as follows.

$$[M]\ddot{x} + [C]\dot{x} + [K]x = f \qquad \text{...(1)}$$

where [M] ...Mass Matrix, [C]...Damping Matrix, [K]...Stiffness Matrix
x...displacement vector, f... force vector.

Then the displacement vector x in *Eq. (1)* is separated as *Eq. (2)*.

$$x = \begin{pmatrix} x_G \\ x_C \end{pmatrix} \quad \text{where } x_G\text{...guide displacement, } x_C\text{...displacement of frame \& cage} \qquad \text{...(2)}$$

The constraint equations between the guide rail displacement d_r and the guide shoe displacements x_G are described in *Eq.* (3).

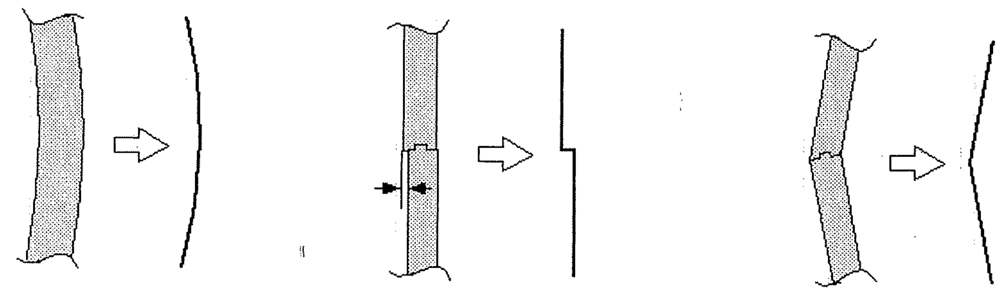
$$x_G + d_r = 0 \qquad \text{...(3)}$$

The constraint forces between the guide shoe displacement and the guide rail displacement can be evaluated by using the Lagrange multiplier method. Then we can evaluate the elevator vibration with a constraint between the guide rail and the guide shoe from simultaneous equations *(1)* and *(3)*. The vibration of the elevator frame caused by the constraint force is transmitted to the passenger cage, which degrades the elevator ride comfort.

We divide guide rails displacements d_r broadly into three categories as follows.

(a) Bending in guide rails ⇒ *approximate to sine wave*
(b) Level difference at joints of the guide rails ⇒ *approximate to step function*
(c) Skew at joints of the guide rails ⇒ *approximate to triangular wave*

These guide rail displacement patterns are illustrated in *Figure 2*.



(a) Bending in guide rail *(b) Level Difference at rail joint* *(c) Skew at rail joint*

Figure 2. Guide Rail Displacements Pattern

By substituting the above displacement patterns for guide rails displacements d_r in *Eq. (3)*, we could examine what kind of guide rail displacement is most significant for ride comfort. As a result of these examinations, we found that the skew at the rail joints has the most serious effect on lateral elevator vibration in the case of the low and medium speeds at which the slide guide shoes are currently used.

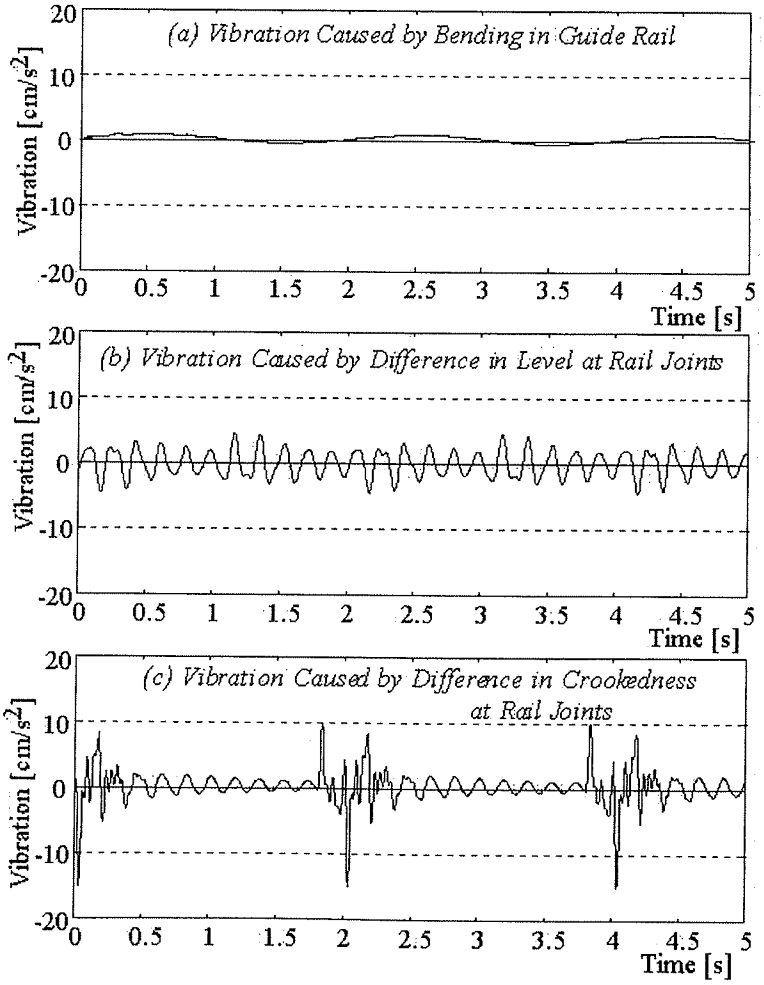


Figure 3. Elevator Vibration caused by Typical Rail Displacement Pattern

3. GUIDE STRUCTURE

3.1 Supporting Structure

A passenger cage is elastically attached with rubber pad to the car frame, which is guided on the rails by the upper and lower guide shoes attached to the frame. One of the conventional slide guide shoe structures is illustrated in *Figure 4*. In order to suppress the exciting force generated at the guide shoes, it is better that the stiffness of support rubber be as elastic as possible. One the other hand, elevator car displacement is limited for various reasons, for example to avoid a collision with other devices in the hoistway, so it is necessary that the support rubber have the precisely appropriate stiffness.

In the case of the conventional slide guide shoe shown in *Figure 4*, the sliding member is held elastically by the support rubber, and the stopper limits its movements in the lateral and rotational directions. To support an elevator car with suitable stiffness as mentioned above, there is a tendency to increase stiffness for rotational support in this type of guide shoe. Actually, there is a type of swivel slide guide shoe that provides a free rotational movement. However, this type of guide's movement is rigidly supported in the lateral direction.

By considering above, we investigated the most suitable supporting structure to achieve the optimum stiffness both in lateral and rotational displacements of the sliding member.

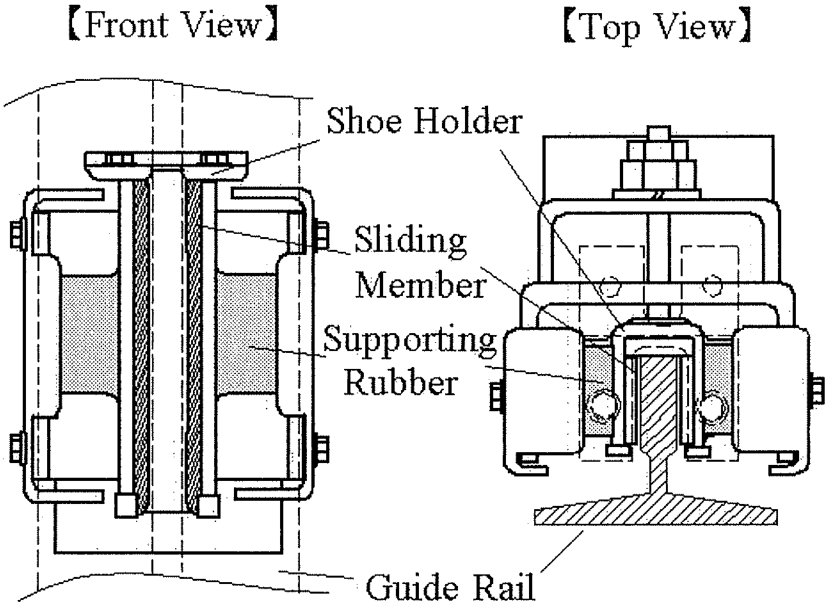
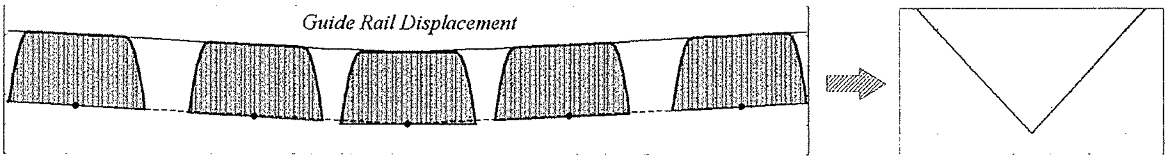


Figure 4. Conventional Guide Shoe Structure

3.2 Specific Shoe Shape

The sliding member of a conventional slide guide usually has a flat surface. *Figure 5(a)* shows the movements of a slide guide shoe with a flat surface sliding member when passing a skew at a guide rail joint. It shows that the movement of a conventional slide guide shoe is equivalent to the guide rail displacement. Therefore, when the guide shoe passes the skew at a rail joint, a huge exciting force is generated at the guide shoe that causes the vibration of the passenger cage.

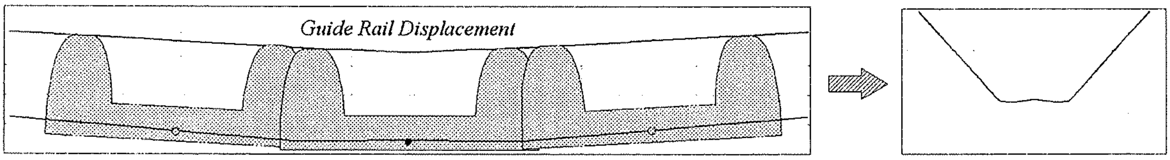
To decrease the exciting force generated in passing the guide rail joint, we designed the shape of the sliding member with a concave surface. *Figure 5(b)* shows the movements of the slide guide with a concave surface sliding member when passing a skew at a guide rail joint. The figure shows that the guide shoe displacement decreases, and its peak is moderated. As a result, the exciting force generated by the skew at a guide rail joint is suppressed, and the passenger cage vibration is decreased.



Flat Surface Shoe Motion Passing Skew at Guide Rail Joint

Simulated Result of Conventional Shoe Motion

(a) Conventional Slide Guide Shoe Shape



Concave Surface Shoe Motion Passing Skew at Guide Rail Joint

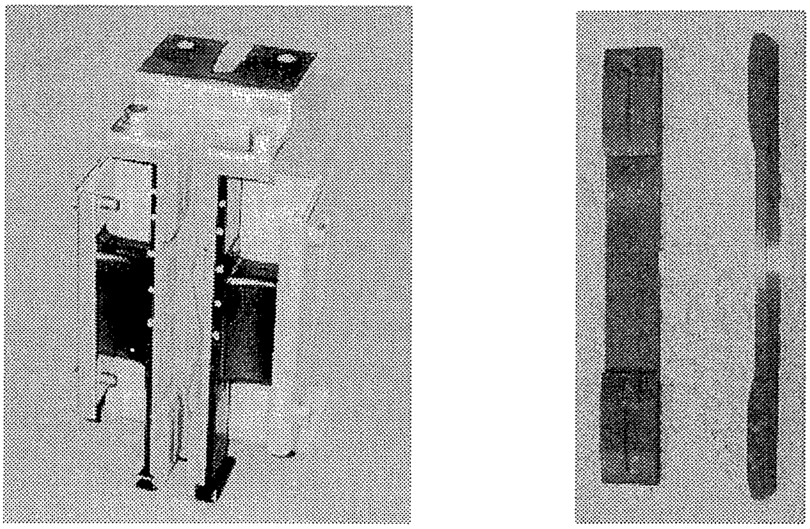
Simulated Result of Concave Surface Shoe Motion

(b) Developed Slide Guide Shoe

Figure 5. Motion of Slide Guide Shoe

3.3 Developed Slide Guide Shoe

The slide guide shoe developed in accordance with the considerations described in *sections 3.1* and *3.2* is shown in *Figure 6(a)(b)*. The sliding member is elastically supported in both lateral and rotational displacement by the optimum stiffness. The supporting rubber form is positioned in the middle of the shoe holder



(a) Overall View *(b) Shape of Sliding Member*

Figure 6. Developed Slide Guide Shoe

4. RESULTS

4.1 Simulated Results

To evaluate the performance of the developed slide guide shoe, we derived an equation of motion for elevator vibration by considering the guide shoe dynamics. The simulated results are shown in *Figure 7* by means of a mathematical model. It shows that the amplitude of vibration caused at the guide rail joint decreased from 37 cm/s^2 for the conventional guide to 21 cm/s^2 for the developed guide.

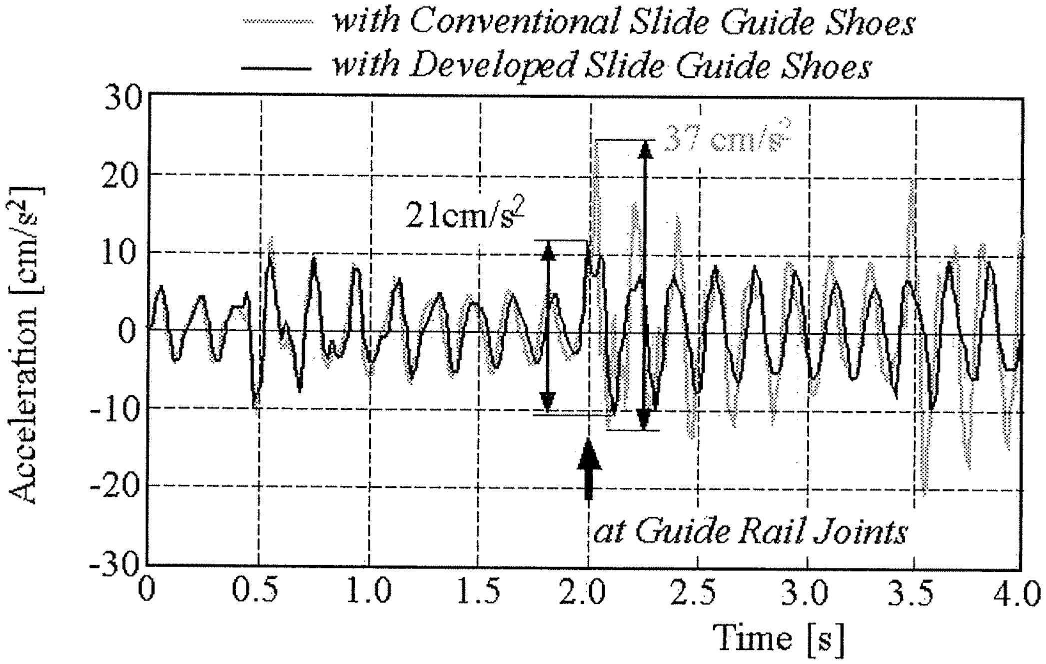


Figure 7. Simulation Results

4.2 Experimental Results

To check the performance of the developed slide guide shoe, we had to conduct experiments with an actual elevator. The elevator guide rail joint was intentionally made skew to observe the guide shoe performance clearly. The experimental results are shown in *Figure 8*. It shows that the amplitude of vibration caused at the guide rail joint decreased from 36 cm/s^2 for the conventional guide to 21 cm/s^2 for the developed guide. These results are consistent with the above simulated results.

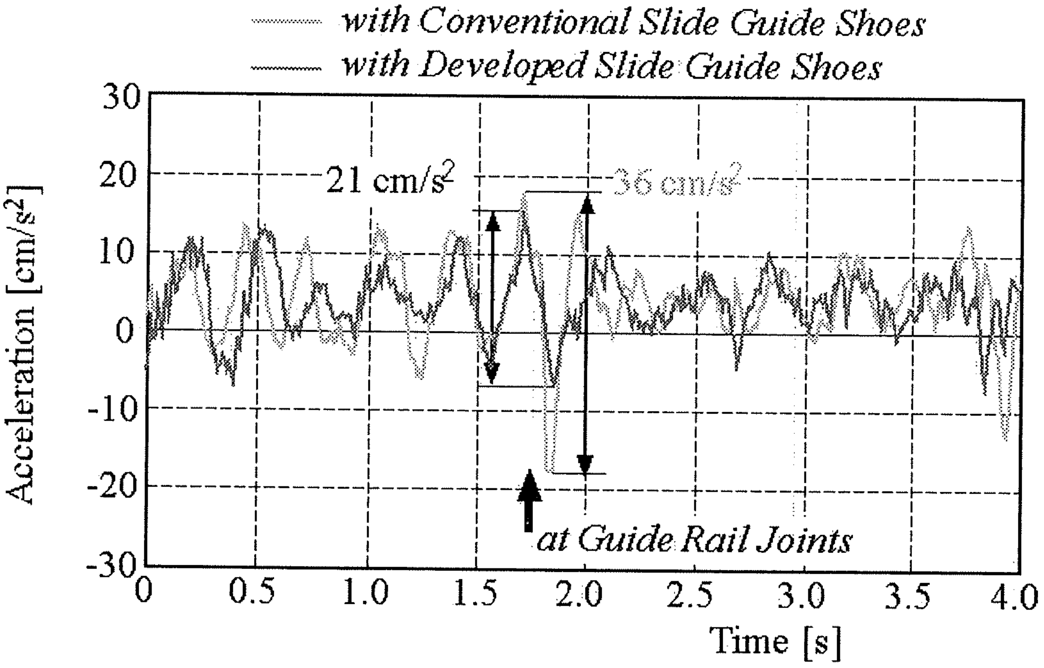


Figure 8. Experimental Results

5. CONCLUSIONS

We presented a new slide guide shoe to suppress elevator lateral vibration generated at the guide shoe. The features of the developed guide shoe are as follows.

(1) The supporting structure has suitable stiffness in lateral and rotational directions of the sliding member.

(2) The design of the specific sliding shoe shape is that of a concave surface.

The design of the guide specifications was examined with a simulation model for elevator dynamics to reduce the time needed to develop the guide shoe.

The performance of the developed slide guide was evaluated by simulation and by experiment. Both types of results showed that the developed slide guide is effective in suppressing elevator vibration caused by the exciting force generated by the skew at guide rail joints.

Biographical details

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