New Mechanical Techniques for Super-High-Speed Elevators

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ABSTRACT

We, at Mitsubishi Electric, are currently manufacturing super-high-speed passenger elevators which are going to be supplied to the Yokohama LANDMARK TOWER Bldg. In order to achieve the expected super-high travelling speed, highly advanced mechanical techniques which involve the reduction of undesired noise and vibration, such as, the aerodynamic noise and car vibration, etc. is indispensable.

In this paper, the results of the wind tunnel experiment performed to evaluate the aerodynamic noise, and also the evaluation performed with our vibration test device for the reduction of car horizontal vibration are described.

1. INTRODUCTION

Mitsubishi Electric Corp. supplied passenger elevators travelling at the world's fastest speed of 600m/min. to the Sun Shine 60 Bldg. in Tokyo in 1977. This world's fastest record has since then not been broken. In Japan, projects to re-develop urban areas are currently ongoing, and due to this fact, the construction of high rise buildings is experiencing a boom period and the demand for high-speed elevators has been increasing. The height of the Sun Shine 60 Bldg. is 240 meters and it had been the tallest building in Japan for a while, but a new building belonging to the Tokyo Metropolitan Government which was constructed in 1991 is 243 meters high and presently the tallest building in Japan. The VVVF-controlled elevators manufactured by Mitsubishi, whose travelling speed is 540m/min., the world's fastest of VVVF-controlled elevators, are in operation in this Japan's tallest building. Meanwhile, the LANDMARK TOWER Bldg. is currently being constructed in Yokohama, and in the near future, this 296 meters high building will be Japan's tallest building as it is completed in 1993. We will supply super-high-speed elevators to this building, whose travelling speeds will substantially surpass 700m/min., and we are currently leading studies and development to manufacture these elevators.

In addition to the conventional techniques that have been adopted in the past, highly advanced new techniques are indispensable in order to manufacture super-high-speed elevators. Highly advanced techniques must always be applied to products, but in addition to this, techniques for evaluating the products are also required, because of the fact that evaluating and testing an elevator in actual travelling operation is difficult at our factory, and specific kinds of devices, such as a simulator, need to be developed for test purposes.

Out of all the studies and techniques involved for super-high-speed elevators, this report focuses on the mechanical techniques. The outline of the techniques being developed for low elevator vibration and noise reduction, together with the designing and evaluation techniques, are introduced hereafter in this paper.

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2. TECHNICUES FOR REDUCING AERODYNAMIC NOISE

2.1 Outline of Aerodynamic Noise

There are two types of noises involved with elevator operation; mechanical noise and aerodynamic noise. Mechanical noise occurs by the contact between an elevator and the rails which guide the elevator. On the other hand, aerodynamic noise occurs by the air flow caused around the car, as an elevator travels through a narrow hoistway. Aerodynamic noise becomes larger in proportion to the 5th through 6th power of the wind velocity around the car. Due to this fact, aerodynamic noise is usually larger than mechanical noise with super-high-speed elevators and it is important to reduce the aerodynamic noise in order to achieve a comfortable elevator ride.

When a car runs, the air flow around the car separates from the car surface at either the top or bottom end of the car, which then re-attaches (flows back) over the side faces of the car. The air flow running over the side faces will then vibrate the entire car body causing undesired noise inside the car. As for the solution for this noise problem, a streamlined cover may be mounted on both the top and bottom faces of the car in order to effectively reduce the air flow separation.

We have performed several experiments, such as the wind tunnel experiment in order to scrutinize the effectiveness of the streamline covers. The details of these experiments are reported in this section.

2.2 Outline of Wind Tunnel Experiment Device

As shown in Fig. 2.1, two streamline covers were mounted on a 1:12.5 scale miniature elevator.

These streamline covers are removable and it is possible to observe the air flow around the elevator with and without these covers. Several holes are provided on side faces of the car, which measures the pressure fluctuation caused by the air flow. A microphone is attached on each hole and the fluctuation in the pressure can be measured by these microphones.

The sectional view and size of a duct, which was made to serve the purpose of a hoistway in this experimental equipments, are shown in Fig. 2.2. The average wind velocity inside the duct is 30m/sec.

An "oil flow pattern method" was applied for this experiment in order to visualize the air flow over the surfaces of the car.

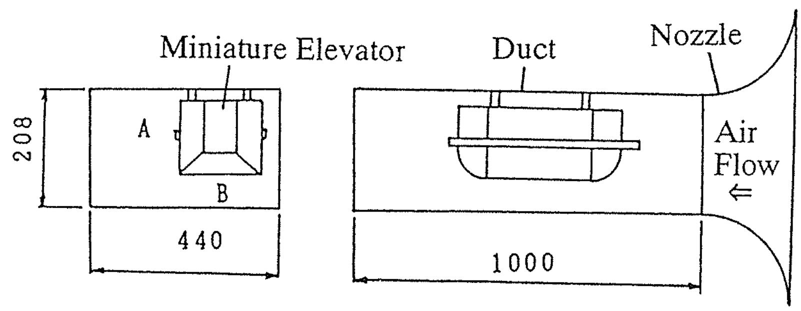

Fig. 2.2: Schematic of Experimental Facility

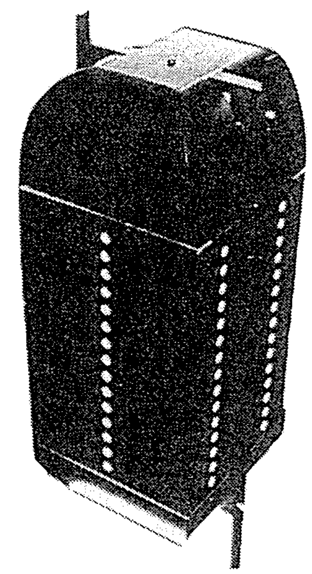

Fig. 2.1: Miniature Elevator

2.3 Result of Experiment

Fig. 2.3 shows the picture of the air flow over the side face of the car without the streamline covers mounted on the miniature elevator. This oil flow indicates that strong air turbulence occurred around this portion of the car.

The picture in Fig. 2.4 show the results of the experiment with the streamline covers mounted on the elevator. In this picture, it is observed that the air flow separated from the car surface at the area where the curvature of the cover changes and the flow re-attaches (moves back) onto the surface immediately after the separation area. Therefore, the air turbulence on the surfaces is smaller in comparison to that occurred without the streamline covers.

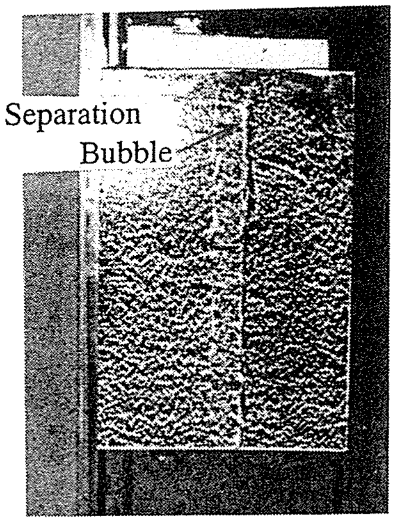

Fig. 2.3: Oil Film Pattern on Car Side Face without Streamline Covers

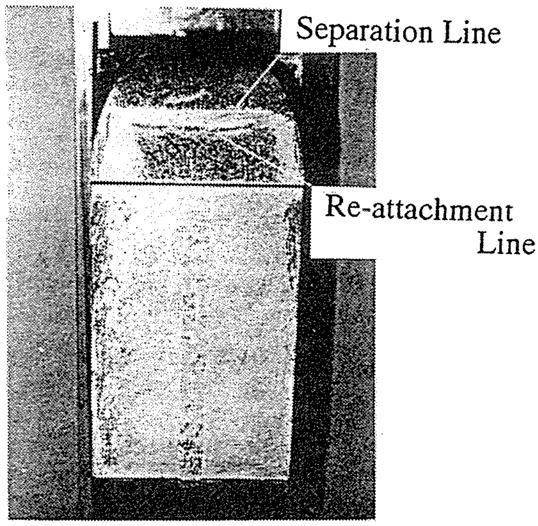

Fig. 2.4: Oil Film Pattern on Car Side Face with Streamline Covers

Fig. 2.5 shows the fluctuation in the pressure generated on the side face of the car. The values in the figure are non-dimensional numbers which were divided by the standard pressure P_0. In this figure, it is observed that the values obtained with the covers are smaller than those obtained without the covers. This result proves that the application of the streamline covers reduces pressure fluctuation down to a half of that produced without the covers.

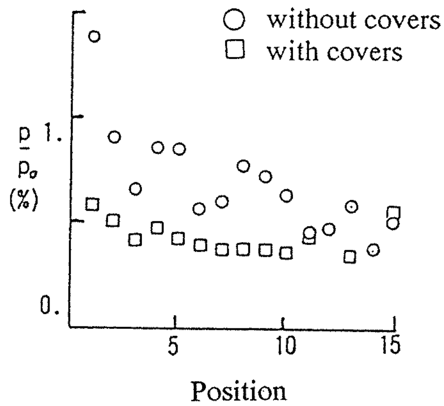

Fig. 2.5: Pressure Fluctuation on Car Surface

Two streamline covers were mounted on an actual elevator in order to confirm the effectiveness of the covers. The frequency analysis of the noise caused inside the car is shown in Fig. 2.6. The effectiveness of the covers for noise reduction, with the elevator travelling at the speed of 540m/min., was 4.3dB(A) when ascending, and 4.1dB(A) when descending.

The elevators with the travelling speeds exceeding 700m/min. require highly advanced techniques for noise reduction. In addition to these streamline covers, we are continuing research of car structure designing so that the car itself will have more effective noise insulation.

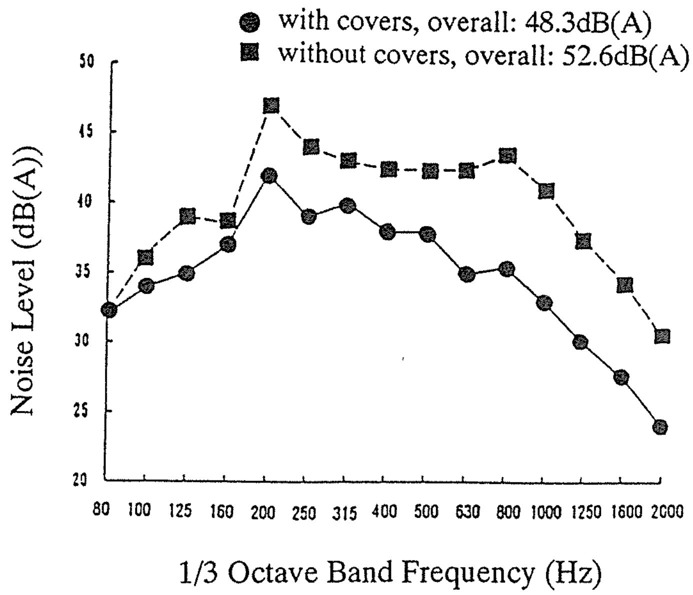

Fig. 2.6: Frequency Characteristics of Interior Noise with Car Ascending

3. TECHNIQUES FOR REDUCING HORIZONTAL VIBRATION OF CAR

3.1 Outline of Horizontal Vibration of Car

Horizontal vibration of the car will occur mainly by the curving of the guide rails. The horizontal vibration increases in proportion to the car travelling speed. Fig. 3.1 shows the relationship between the car travelling speed and the degree of horizontal vibration, which was observed through the experiment using an elevator whose rated travelling speed is 540m/min. As this example shows, the horizontal vibration of a car increases in proportion to the car travelling speed. This fact makes it clear that reduction in car vibration plays a vital role to achieve a comfortable ride with super-high-speed elevators, in addition to the noise reduction already reported.

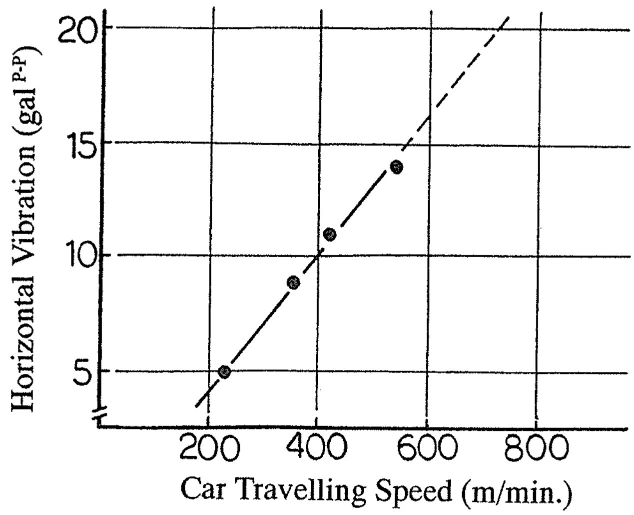

Fig. 3.1: Example of Relationship between Car Travelling Speed and Horizontal Vibration

One of the studies now being carried out for manufacturing super-high-speed elevators is the study to minimize this horizontal vibration. There are two countermeasures which can be taken in order to reduce the vibration; one is the reduction of the curving degree of the guide rails, which is actually the source of the vibration, and the other is the improvements in the vibration characteristics of the car. We have focused on the improvements in the vibration characteristics, and for the research, the simulation using a vibration test device was performed. A finite element program "NASTRAN' was applied to the simulation in order to calculate the optimum spring constant and damping constant for the guide rollers and also to predict the effectiveness of improvements in other areas(1). The vibration test device was developed especially for this research and enables to simulate a car in travelling motion even inside our laboratory.

3.2 Vibration Test Device

Fig. 3.2 shows the external view of the vibration test device and the overall configuration of the device is shown in Fig. 3.3. An actual car is hung from the frame with ropes and hydraulic cylinders vibrate the car horizontally. The cylinders are servo-controlled and are able to be driven by any type of waveform generated by a waveform generator. Also, they are able to be driven by the waveform of the curving of guide rails fed from a data recorder, which was actually measured prior to the simulation. As for data analysis, we applied the software "TDAS". By this application, prompt data process for vibration analysis can be easily performed.

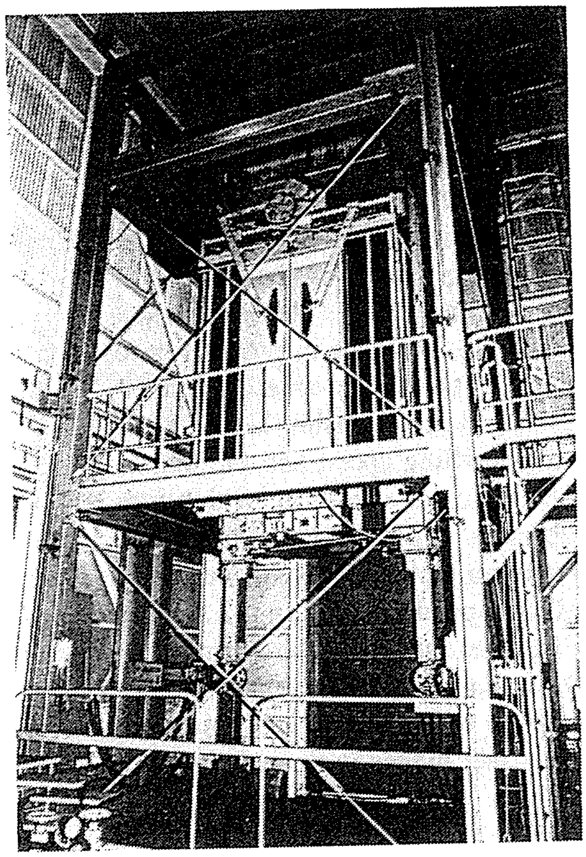

Fig. 3.2: External View of Vibration Test Device

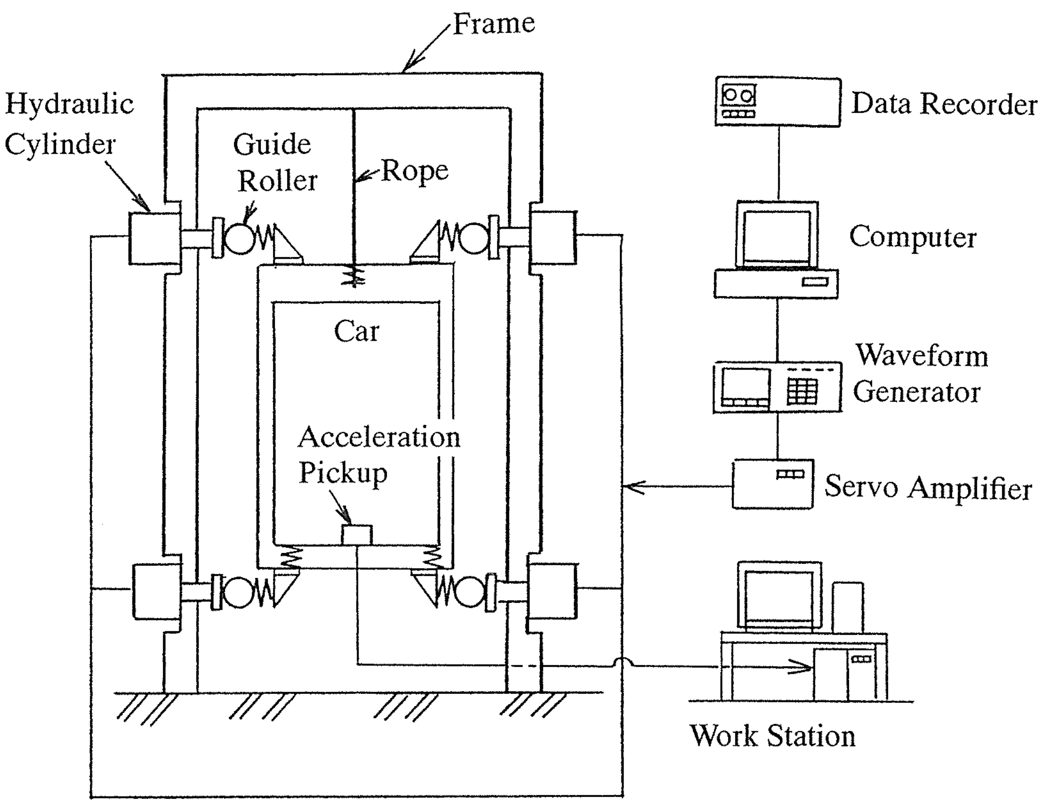

Fig. 3.3: Overall Configuration of Vibration Test Equipment

From the application of this vibration test device, it has become easier to obtain information such as car natural frequency, damping constant and vibration mode, and the simulation of the car in travelling motion is made possible inside our laboratory by vibrating the car with the actual waveforms of the curving of guild rails. In addition to this, the car can be simulated for any travelling speed, by processing the inputted waveforms of the curving of guide rails. By using this simulation equipment, it is possible to easily evaluate the car horizontal vibration which may occur by moving the car at a super-high-speed which until now has never been achieved. Fig. 3. 4 shows the data of the horizontal vibration of a travelling elevator (car) which was obtained through actual elevator operation at a customer's site, and also those obtained through our simulation performed at our laboratory. The results are very close to one another, and this fact proves that our simulation equipment is able to simulate elevator operation which is virtually the same as actual elevator operation.

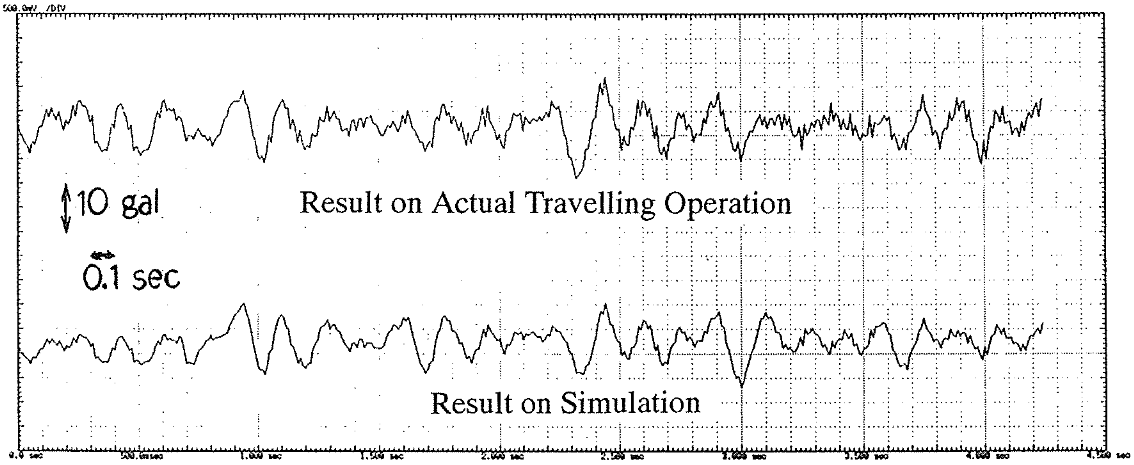

Fig. 3.4: Data of Horizontal Vibration

3.3 Example of Improvements in Car Horizontal Vibration

By using the aforementioned vibration test device, the effectiveness of several improvement methods for reducing the car horizontal vibration was evaluated. Fig. 3.5 shows one of the results obtained through the simulation. In this figure, the results of the simulation where the optimum spring constant and damping constant of the guide rollers were applied, and also with dampers mounted between the car and car frame, are indicated. By making improvements in these factors, the vibration has been reduced approximately by 30%.

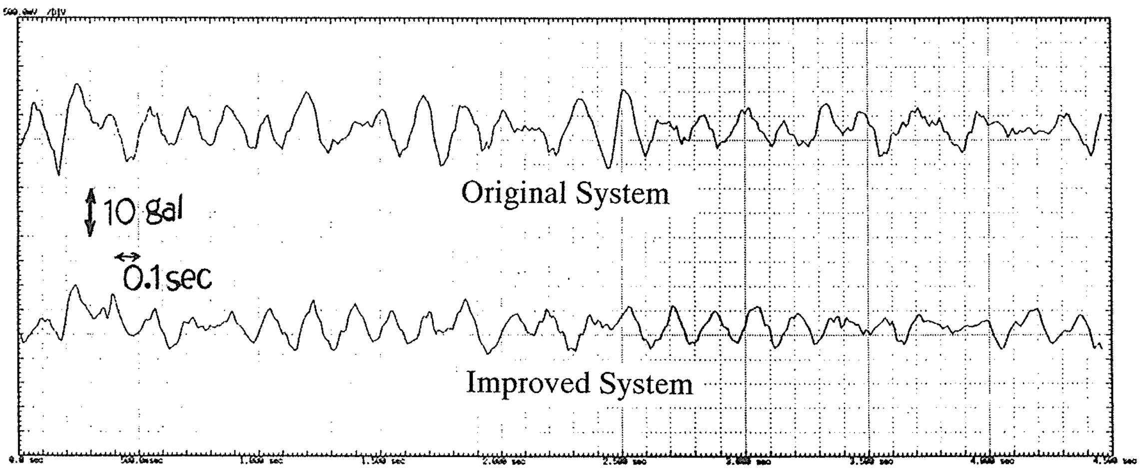

Fig. 3.5: One of the Results Obtained through Simulation

In addition to the above mentioned simulation, we performed simulation where oil dampers were mounted on the guide rollers instead of conventional friction dampers, and also where active vibration controllers are mounted on the car, etc. After evaluating several improvement methods, it was concluded that reducing the car horizontal vibration to a large extent is possible, even for elevators whose travelling speeds exceed 700m/min.

4. CONCLUSION

The outline, evaluation methods and results of the highly advanced techniques, which were applied to reduce aerodynamic noise and horizontal vibration, for the purpose of achieving super-high-speed elevators, were introduced in this paper. Our super-high-speed elevators currently being developed will break the latest world's fastest record and will leave a remarkable record in elevator history. It is, however, predicted that the trend toward taller buildings will continue to grow, and due to this fact, the world's fastest record will be continuously renewed. In addition, the conceptions of constructing buildings taller than 1,000 meters have been announced to public recently in Japan. Elevators not only with super-high-speed performances but also with different concepts from those of conventional elevators will be applied to these super high skyscrapers. To meet these highly technological demands of the future, we, at Mitsubishi, are dedicated to providing continual research, development and manufacturing of super-high- speed elevators.

Document for Reference

(1) Y. Sugiyama, et al: IMPROVEMENT OF RIDE COMFORT AGAINST HORIZONTAL SWAY, ELEVATOR TECHNOLOGY III (1990)

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