Project Spotlight

BREAKING THE 1,000MPM BARRIER

High-Speed Elevators in Taipei 101

by Hiroaki Mizuguchi, Toshiaki Nakagawa and Yoshiaki Fujita

Introduction

The pursuit of a comfortable ride in higher-speed elevators has been progressing remarkably in the past 20 to 30 years. The process of this development is as follows:

- 488mpm at the Sears Tower and the former World Trade Center
- 549mpm at the John Hancock Center
- 600mpm at the Sunshine 60
- 750mpm at the Landmark Tower.

The growing number of high-rise buildings is accelerating elevator running speeds. At last, an elevator that exceeds 1,000mpm has arrived.

Toshiba Elevator and Building Systems Corp. has installed a total of 111 elevators, including 34 double-deck elevators (with two linking cars), two world-record high-speed elevators of 1,010mpm (60.6kph) and escalators in Taipei 101 in Taiwan. Taipei 101 is the world's tallest building at 508 meters. Its height exceeds that of the Petronas Tower in Kuala Lumpur, Malaysia.

Taipei 101's 1,010mpm elevators run from the ground to the 89th floor in only 39 seconds, and from the top floor to the ground in only 48 seconds. This speed was recorded as a Guinness World Record on December 16, 2004.

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Figure 1: History of the high-speed elevator

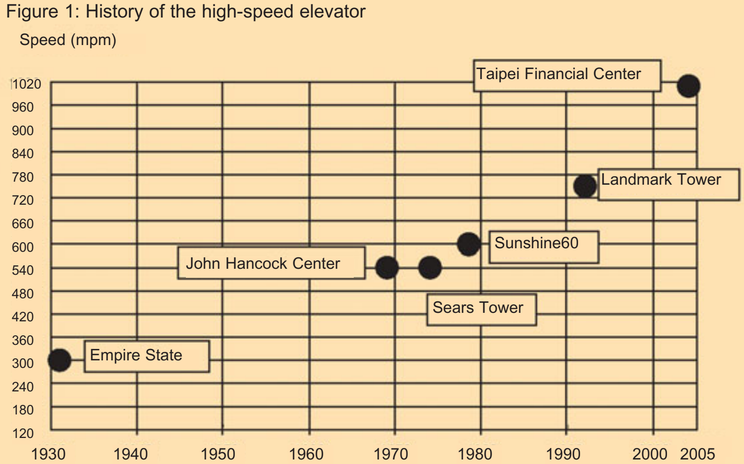

Figure 2: An overview of Taipei 101

Figure 3: The outline of Taipei 101

Taipei 101	
101 Floors	
508 meters high	
Elevators & Escalators	
Number of Elevators	61
Ultra-High-Speed Elevators	2
Double Deck Elevators	34
Other Large-Capacity Elevators	25
Number of Escalators	50

Figure 4: The specifications for Taipei 101's high-speed elevator

Passenger Capacity	24 Persons
Rated Capacity	1600kg
Rated Speed	
	UP: 1,010mpm
	DOWN: 600mpm
Control	AC Gearless
Travel	382.2 meters
Service Floors	1,4,5,86,88,89

Toshiba used many advanced techniques for these world-record high-speed elevators:

1) The driving system for a powerful traction machine and a twin drive controller
2) The car equipment enabling a comfortable ride at high-speed operation
3) The system that ensures the safety of a car with passengers

These systems are shown in Figure 5.

Driving System

Traction Machines

Construction has been simplified and high-speed traction machines made as small as possible in the minimized permanent magnet synchronous motor.

The newly developed traction machine, shown in Figure 6, has 168KW of rated output and 1,186KW of maximum output. The axle weight bears a maximum of 77 tons. Toshiba adopted a special frame to avoid vibrations caused by electromagnetic force. It has no accompanying resonance due to the optimization of a magnet configuration under acceleration or deceleration at 1,010mpm.

Moreover, Toshiba adopted a double multi-step vibration-proofing construction to support the traction machine. The vibration insulation is twice that of conventional insulation.

Controller

A highly efficient microprocessing unit exclusively for power electronics was miniaturized, and control panel throughput was conducted. Furthermore, Toshiba developed a controller to drive the motor and adopted the twin drive system. These drive units independently control the converter/inverter using two lines in order to drive a powerful two-winding traction machine. This allows very precise control. Moreover, the main-circuit conversion device of this drive system has a 1,200 V-600 A-class insulated gate bipolar transistor element with six parallel connections using one phase. The driving system has a twin drive machine. Thus, the maximum output is 650KW using one drive, making the total output 1,300KW.

Car Equipment

Atmospheric Pressure Control

Atmospheric pressure change has a physiological effect on passengers; this is a new technical issue concerning high-speed elevators. In Taipei 101, the high-speed elevator travels at 1,010mpm going up and 600mpm going down over a distance of 382.2 meters. The atmospheric pressure difference between the dispatching floor and the destination floor is set to about 48 hPa. Rapid atmospheric pressure change may normally cause passengers' ears to pop, which feels very uncomfortable. For this reason, Toshiba developed an atmospheric pressure regulating system. In the Taipei 101 project, the system was applied for the first time in an elevator. A comfortable ride was realized by applying an atmospheric pressure regulating system when the monitor test was repeated.

As a result, we adopted a regulating pattern with the rate of atmospheric pressure change fixed at the same value shown in Figures 7a and 7b. The measurement results are shown in Figures 8 and 9, where atmospheric pressure reaches the maximum rate of change after changing slowly at first. Then the change accelerates, and finally slows down again.

A pattern with the rate of atmospheric pressure change fixed at the same value from start to stop is the most desirable. The rate of atmospheric pressure change in an ascending car was sharply reduced to about 1.29 hPa/sec and also reduced during the descent to a level of 0.96 hPa/sec. The high-pressure blower generates the compulsory pressure. In addition, the car has a double-panel construction to make it more airtight and to prevent deformation caused by the added atmospheric pressure load. By controlling the atmospheric pressure difference between the inside and outside of the car, a good performance was obtained for the controller that set a constant atmospheric pressure change.

Aerodynamic Capsule

Wind noise is generated when running in a hoistway and is similar to that of a train running in a tunnel. Wind noise energy is equivalent to about six times the power of the running speed. Though it is generally negligible, wind noise becomes a factor at the great speed of 1,010mpm. Thus, Toshiba analyzed air pressure in the hoistway when the elevator was running. The aerodynamic performance of the capsule was analyzed, showing that the streamlined design reduced wind noise.

The entrance section, in particular, has relatively loose sealing because of the opening and closing operations of the door panels. Thus, there is external noise in the car. For this reason, the top spoilers of the wedge configuration attached to both ends (the top and the bottom) of the capsule were improved. Most of the airstream produced as the car runs escapes to the side or back of the car. The top view of an aerodynamic capsule is shown in Figure 10. By use of an aerodynamic capsule, Toshiba was able to reduce the noise level to the same as that of a conventional 600mpm elevator.

New Roller Guide

Minute deflections on a rail affects an elevator's forcible displacement and aerodynamic force. This causes lateral vibration of the car. Generally, since

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Figure 5: Technical subject

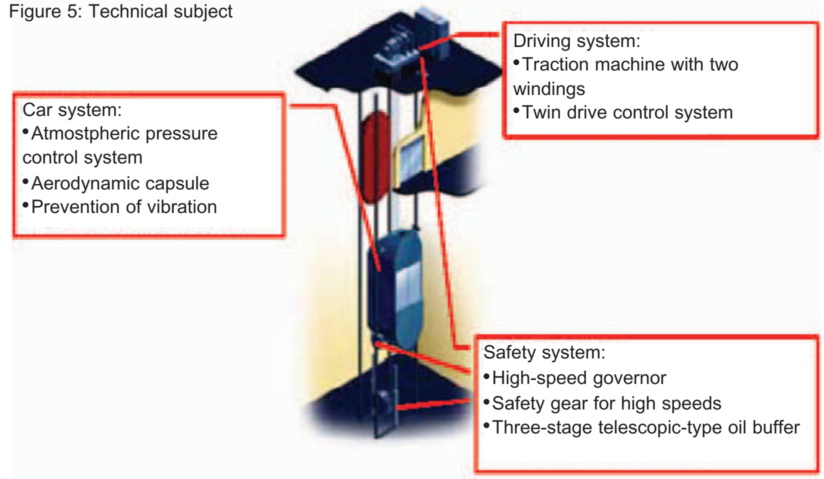


Figure 6: A powerful traction machine

Figure 7a: Car pressure variation up

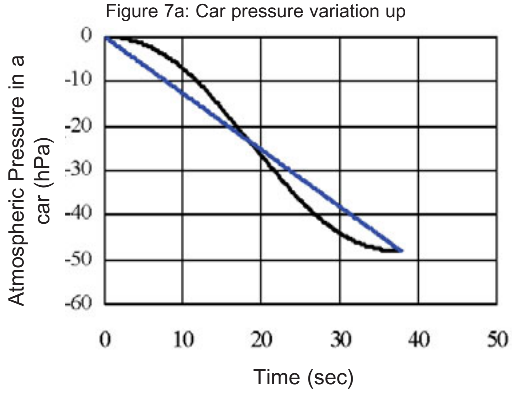


Figure 7b: Car pressure variation down

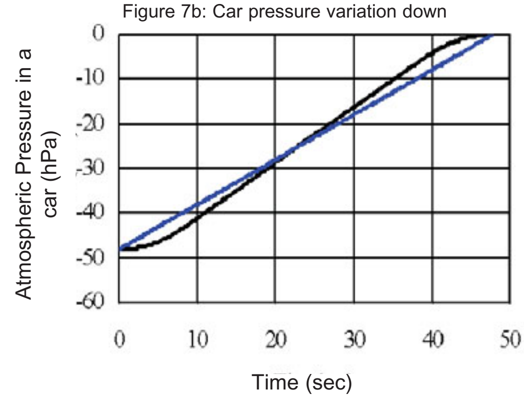


Figure 8: Result of atmospheric pressure control

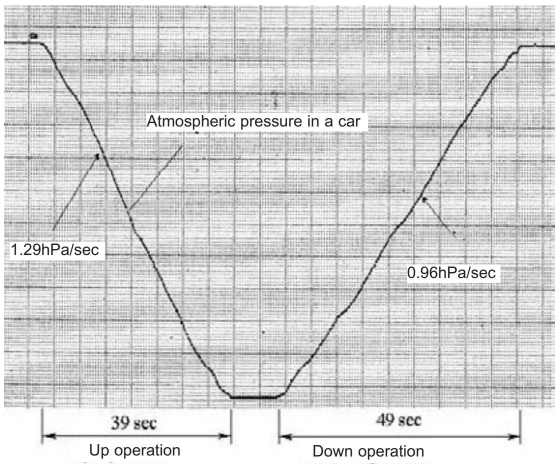


Figure 9: Result of no-control "S" pattern

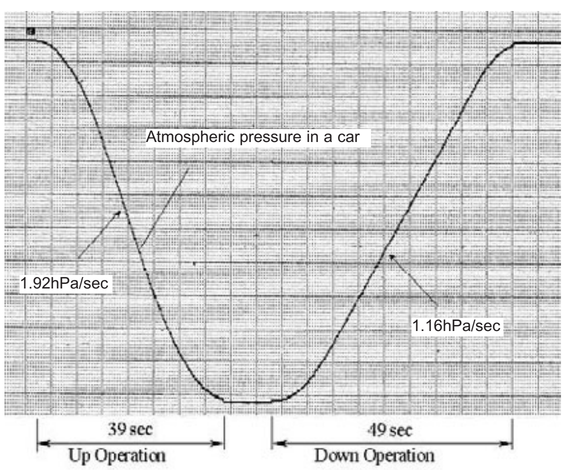
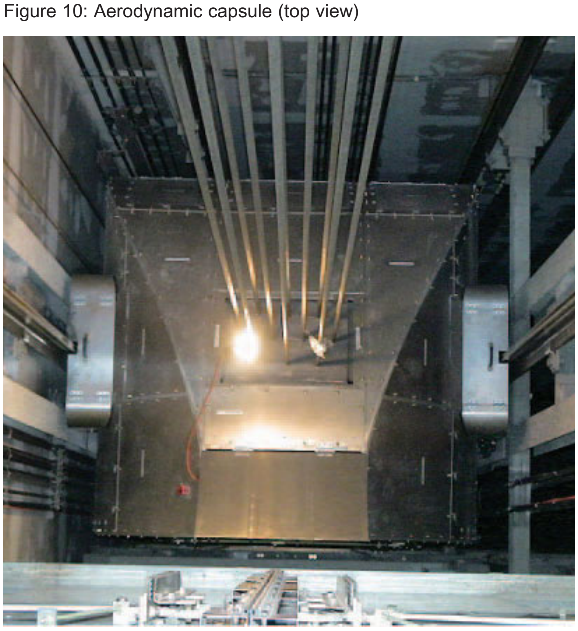


Figure 10: Aerodynamic capsule (top view)



vibration in the car increases when running at ultra-high speeds, vibration control with only conventional vibration-proofing construction does not perform sufficiently, and a new vibration isolator for ultra-high-speed elevators is needed. Figure 12 shows the new roller guide developed for ultra-high-speed elevators.

Bends or distortions of the guide rail cause compulsory force to the car. When it runs at ultra-high speeds, the frequency of displacement rises. A balance weight is loaded in the lever bottom of the guide roller to input the high frequency canceled in the mechanism. In addition, an interference spring absorbs all the working force from the guide roller. The force does not work on the rocking shaft (bearing) of a lever. The transfer of forced pressure can decrease to 25% up to 10 Hz, and to 65% at 20 Hz compared with that of a conventional elevator.

Vibration Control

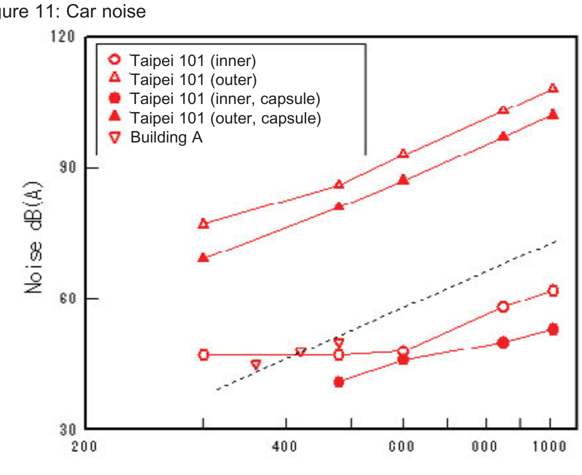
Toshiba aimed at keeping this below 10cmps2 (p-p), a figure that can be assumed as the optimal level for the lateral vibration of a car when running at 1,010mpm. Consequently, the new roller guides reduce the amount of vibration transferred to the car, and the mounted active mass dampers (AMD) reduce vibration even if sudden disturbances affect the car. If the vibration of the car is detected by the acceleration sensor, the AMD drives a movable weight using a motor and actively controls the car vibration. Toshiba considered the stability of the control to be important, so a sky hook damper control was adopted.

Figure 13 shows the measurement data concerning the lateral (from side to side) vibration of the car when the elevator is ascending at 1,010mpm. The vibration of a car is less than 10cmps^2 (p-p) during operations, which is barely perceptible to passengers. This is dependent on the precise installation of the guide rails and the effect of the newly developed roller guides. In addition, the movement of the AMD weight is small under normal running conditions, and the differential AMD control, whether on or off, is barely perceptible.

Vibration When Cars Pass Each Other

Wind pressure laterally vibrates a car when it passes another car, or when there is a counterweight or an adjacent car. First, in passing another car or a counterweight, the air that acts between mutual cars

Figure 11: Car noise



is reduced by installing a thin, long counterweight. In addition, Toshiba created as large a gap as possible between the car and the counterweight. An aerodynamic capsule is also attached in a counterweight other than a car. As a result, lateral vibration is remarkedly reduced.

Toshiba also developed the AMD that actively controls lateral vibration. It applies the reverse direction force of the vibration to a passing car. With AMD, momentary vibration by an adjacent passing car decreases to 33% or less for the first shock. Even a coin standing straight up inside a car does not fall down.

Emergency Operation in the Case of Earthquakes or Strong Wind

Skyscrapers undergo strong vibration during earthquakes and strong winds. Toshiba has included countermeasures to minimize damage during these natural events.

Seismic Emergency Operation

Seismic emergency operation stops an elevator at the nearest floor and prevents damage by the ropes making contact with seismic detectors. One P-wave sensor detector was put in the pit area and an S-wave sensor detector was put in the machine room.

Strong Wind Emergency Operation

The strong wind emergency operation mechanism slows or stops an elevator at the nearest floor, which prevents damage by the ropes making contact with building displacement sensors. This device was put in the machine room, as shown in Figure 15.

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Figure 12: A newly developed roller guide

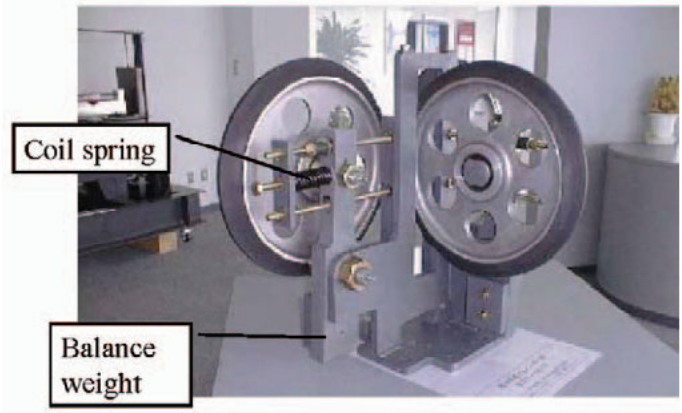


Figure 13: Car acceleration (up)

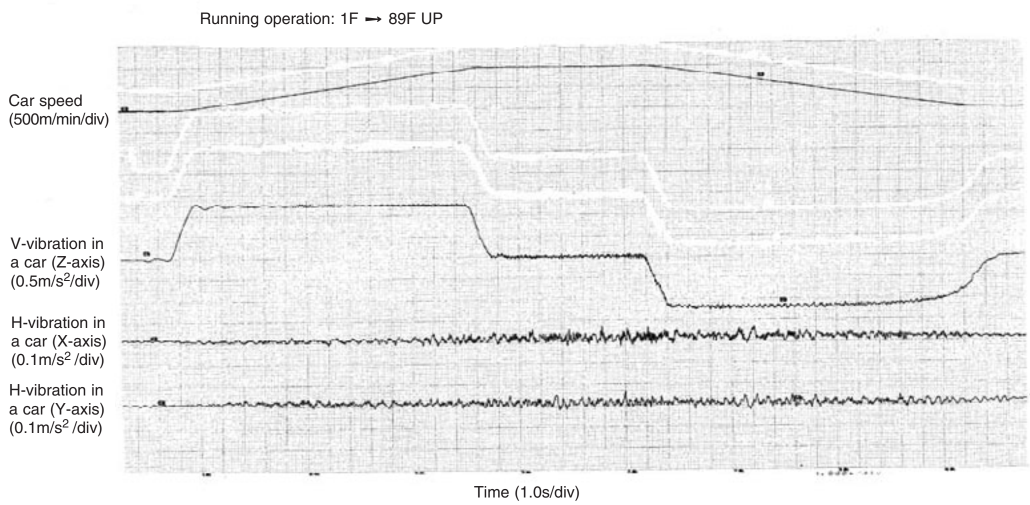


Figure 14: Vibration by the wind pressure at the time of the car passing each other

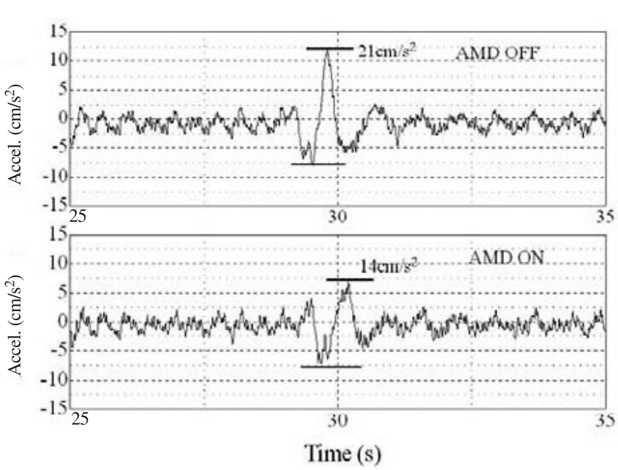
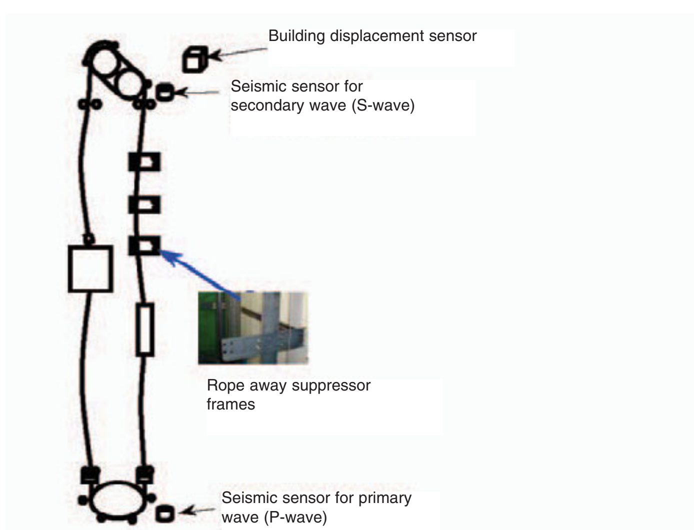


Figure 15: The countermeasure for an earthquake or strong wind



Forecast

As stated so far, various technical subjects are typically researched in high-speed elevators in high-rise buildings to counter severe conditions. For example, these technical subjects can include a broader application of the driving technique of an efficient mass traction machine, vibration control and noise control. Considering the catastrophic damage of recent earthquakes, many more safety measures against them are required. These technical subjects are not only restricted to high-speed elevators in high-rise buildings; they are also common to middle- or low-speed elevators. Moreover, not all the technical subjects in an elevator were solved by this development.

The need exists to further improve based on user-friendly design through the inclusion of riding comfort. Toshiba will make every effort to incorporate customers' needs into its elevator-related research and production.

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