Drive Control Equipment for 750m/min.(12.5m/sec.) Elevators

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ABSTRACT

A variety of advanced technologies were applied to the world's fastest passenger elevators travelling at speeds of 750m/min., which were delivered to the LANDMARK TOWER Bldg. in Yokohama (opened in July, 1993.) The devices, newly developed for the elevators, include: 1) highly advanced "VVVF inverter drive control units" and the traction machines driven by the units, 2) safety devices, such as safety gears and oil buffers, 3) roller guides to control cars' horizontal vibration and 4) special car structure to reduce aerodynamic noise which occurs when the car moves.

The details of the technologies and the products' performance regarding 1), 3) and 4) are introduced hereafter in this paper.

1. INTRODUCTION

In 1978, we, Mitsubishi Electric Corp., supplied the then world's fastest passenger elevators, which travelled at speeds of 600m/min., to the SUNSHINE 60 Bldg. in Tokyo. This world's fastest speed record had, since then, not been broken, but by supplying 3 elevators (2 of capacity 1600 kg, 1 of capacity 950kg) which travel at speeds of 750m/min. to The LANDMARK TOWER Yokohama (see Fig. 1), we broke the previous world's fastest record and made a remarkable speed improvement which had not been achieved for the last 15 years.

For the super-high-speed elevators travelling at 750m/min., highly advanced new technologies were crucial in addition to the conventional technologies adopted in the past. We have focused mainly on the following technologies during the development for super-high speed elevators.

(1) Development of traction machine and drive control system
(2) Development of safety devices which can withstand the increased stop energy
(3) Control of vibration which occurs when travelling at super-high-speed
(4) Reduction of aerodynamic noise

Fig. 2 shows the primary devices developed for The LANDMARK TOWER Yokohama, which were made to meet the above shown requirements. The outline of the technologies behind these devices are introduced hereafter in this paper.

2. ELECTRICAL CONTROL SYSTEM

It is imperative to employ large-size traction machines and inverters of larger capacity for the elevators travelling at the super-high-speed of 750m/min. The characteristics and performance of the newly developed electrical control system are introduced in this section.

2.1 Traction Machine

The traction machine developed for the super-high-speed elevator for long hoistway travelling employs an AC motor with large power capacity, 120 KW with 8 poles, which forms a gearless structure. 10 ropes, each of 18mm in diameter, are used as the travelling is long and the load to be applied to the elevator becomes large. Noises are generated when operating the super-high-speed elevator. With regard to the traction machine, magnetic noise is caused by the AC motor and also meshing noise is caused by the sheave as it rolls in/out the ropes. In order

MOTOR CONTROL			
	JOB	LANDMARK TOWER	SUNSHINE 60
MACHINE	SPEED	750m/min	600m/min
	OUT PUT	120K W	103K W
	RPM	240	195
	WEIGHT	12.5ton	8.7ton
	TYPE	AC GEARLESS	DC GEARLESS
CONTROL	MOTOR DRIVE	VVVF INVERTER	WARD LEONARD employing MGsets
	CONTROL	DIGITAL CONTROL with MICRO-PROCESSER	ANALOGUE CONTROL using ANALOGUE DEVICES

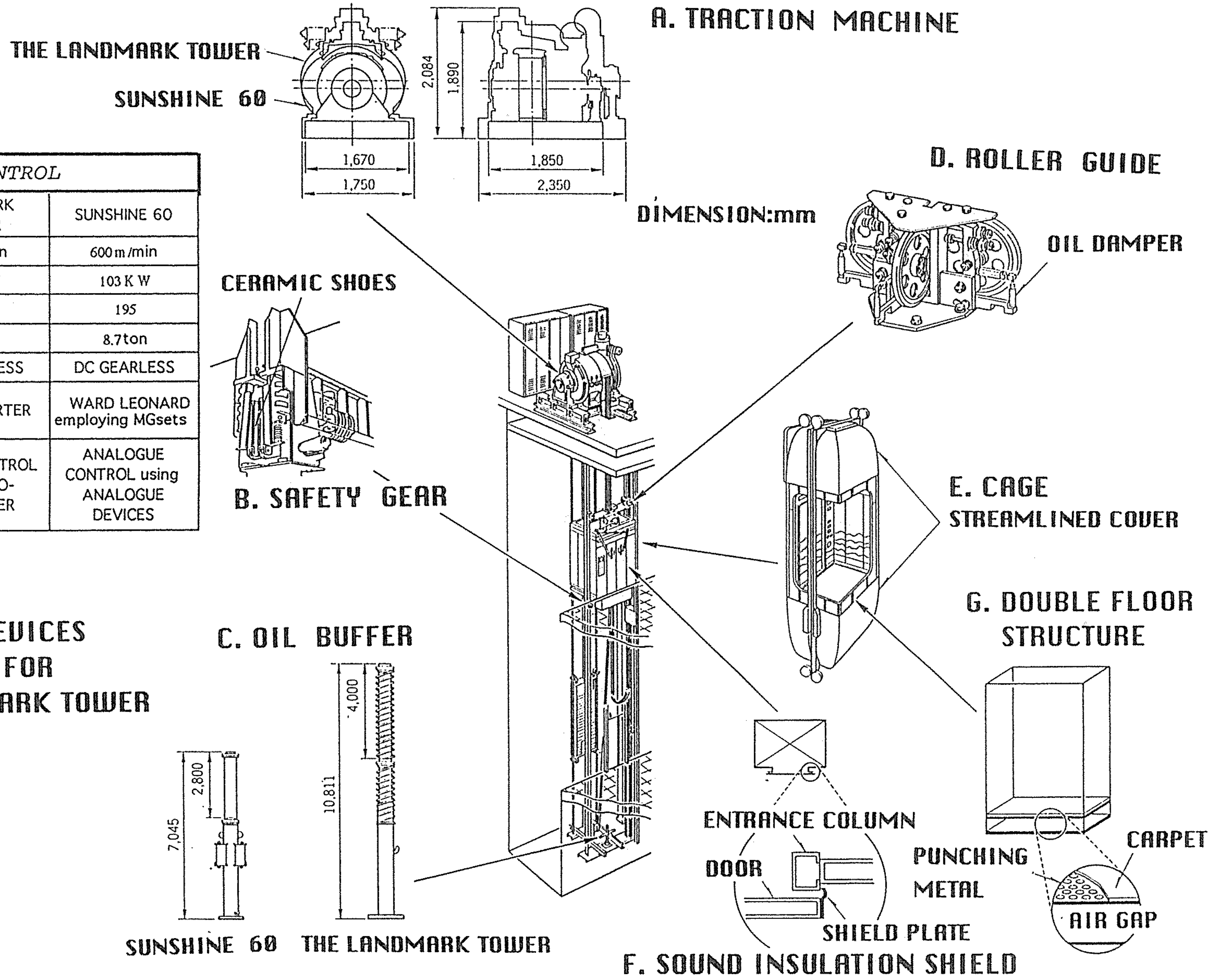

FIG.2 PRIMARY DEVICES DEVELOPED FOR THE LANDMARK TOWER

to reduce the magnetic noise, we have reinforced the rigidity of the motor and also selected the optimum number of slots. For the meshing noise, newly developed low-noise ropes were employed, and as a result, the noise was reduced down to the same level as that of conventional high-speed elevators travelling at speeds of 540m/min.

The differences in the specifications between the traction machine for The LANDMARK TOWER Yokohama and that for The Tokyo SUNSHINE 60 are shown in Fig. 2-A. The traction machines for The LANDMARK TOWER Yokohama are the largest we have ever used at Mitsubishi both in output capacity and weight.

2.2 Drive Control System

The configuration of drive control system is shown in Fig. 3. The system consists of; 1) a receiving panel with a deion breaker, 2) reactor panel #1 equipped with input AC-reactors, 3) power panel equipped with converters, 4) control panel equipped with inverters, and 5) reactor panel #2 equipped with output AC-reactors. PWM (pulse width modulation) method to form sinusoidal wave is applied to the converters in order to dramatically reduce the harmonic current.

2.2.1 Parallel Drive Method

The inertia in the rope drive system becomes large as the travelling of this super-high-speed elevator is 267-meter long. Due to this large inertia, excessive current flows through the inverters during the elevator's acceleration. In order to avoid this, we connected six 300A transistor modules in parallel for the converters/inverters. The current between transistor modules can not be balanced if 6 transistor modules are connected all together in parallel, so we connected 3 transistor modules separately in parallel and linked them to the motor (2 sets of 3 transistors) through the reactors.

When inverters/converters are connected in parallel, the current will circulate between the inverters/converters. If excessive current circulates, the inverter/converter output will drop causing a reduction in the acceleration of the elevator. In order to avoid this problem, we have mounted the reactors on the output side (or input side) of both sets of inverters/converters to control the circulating current. In addition, we mounted a digital signal processor to control both sets of inverters/converters. The processor detects the circulating current from the feedback signal of the current output from each inverter/converter, and performs the calculation to control the circulation. The function of the processor resulted in the circulating current staying within 5% of the rated current.

2.2.2 Control Circuit

Each control circuit of inverters/converters is provided with a high-performance digital signal processor which enables accurate drive control. Thus the converters constantly output a stable DC voltage by the "feedback loop control method", detect the phase of the power source voltage and control the input current to make the power factor +1 for the power running and -1 for the regenerative mode. In the inverter control circuit, a high-resolution pulse encoder is employed for the speed feedback loop, and high speed response is made possible by applying a minor current control loop. Since the elevator travels at super-high-speed, the diameter of the traction sheave has become large, which makes the sheave rotation low during landing operation. In order to achieve higher resolution of the speed feedback signals even during low speed operation, we improved the speed detection circuit.

2.2.3 Reduction of Torque Ripple of Motor

The vertical vibration of the elevator car increases when the frequency of the torque ripple of the motor coincides with the natural frequency of the mechanical system. In order to reduce the vertical vibration, it is important to improve the mechanical system and also to reduce the torque ripple by the following methods.

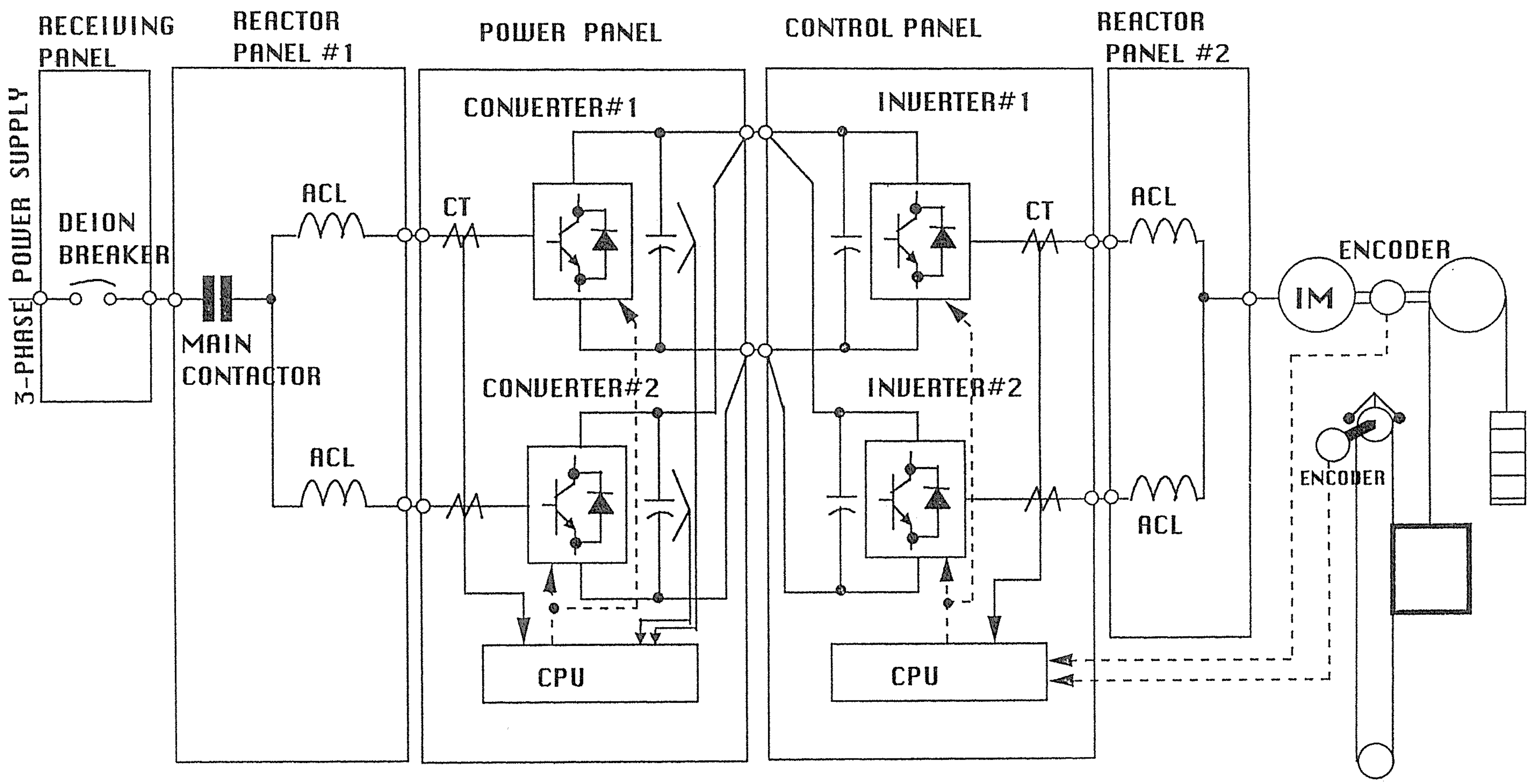

Fig.3 CONFIGURATION OF ELEVATOR DRIVE CONTROL SYSTEM FOR 750M/MIN

(1) A function to automatically compensate the off-set voltage of the DC current transformer to which a hall device is applied.
(2) A function to compensate the voltage disturbance caused by the inverter's dead time function (the function which was designed to prevent the transistor from short-circuiting).
(3) Reduction of the operational cycle time of the control circuit to achieve a quick response, and a function to automatically change the gain (in the control system) for each speed.

2.2.4 Speed Pattern Method

The position of the elevator car is constantly detected to approximately 0.4mm by calculating the pulses generated by the rotary encoder mounted on the governor. The car control micro-computer calculates the distance between the thus detected car current position and its landing position. For conventional elevators, the speed pattern is calculated by the "table-look-up method" according to the calculated distance, but for super-high-speed elevators this method can not be applied since the memory occupied by the tables increases in proportion to speed to the power of two. For this reason, we combined the "table-look-up method" and "multiplication method" to reduce the memory occupied and to achieve a highly accurate speed pattern method.

As the travelling distance is very long, the calculated distance between the car current position and the landing position will not equal the actual distance due to the creeps (expansion/contraction) of the ropes. Due to this fact, it would be impossible to calculate the proper speed pattern, and, as a result, the car will not land accurately. In order to avoid this problem, a function to automatically compensate the speed pattern according to the distance was applied in order to ensure optimum speed patterns at all times. Furthermore, the car position within the landing zone is detected by the position detectors mounted in the hoistway and the optimum landing pattern is selected in order to ensure the desired landing accuracy.

2.3 Measurement of Car Operation Waveform

Fig. 4 shows the car speed and its acceleration performance measured inside the car while travelling at 750m/min. The figure indicates that the car travelled from the 2nd floor to the observation room at the 69th floor in approximately 40 seconds, with a comfortable ride and achieving an accurate landing.

3. SAFETY DEVICES

Safety gears and oil buffers are the most indispensable safety devices for elevators. Fig. 2-B and 2-C show the external views of the safety gear and buffer which were newly developed for The LANDMARK TOWER Yokohama. Details are reported separately in the paper "Safety Devices for 12.5m/sec. Elevators".

4. TECHNOLOGIES FOR REDUCING HORIZONTAL VIBRATION

Horizontal vibration of the car will occur mainly by the curving of the guide rails. The degree of horizontal vibration varies depending on the degree of forced displacement, frequency of the displacement and the vibration characteristics of the car. The horizontal vibration increases in proportion to the car travelling speed, and this fact makes it clear that the reduction of car vibration plays a vital role in achieving a comfortable ride with super-high-speed elevators. Two countermeasures were taken to reduce this vibration; one is the reduction of the curving degree of the guide rails, which is a major cause of vibration, and the other is the improvements in the vibration characteristics of the car.

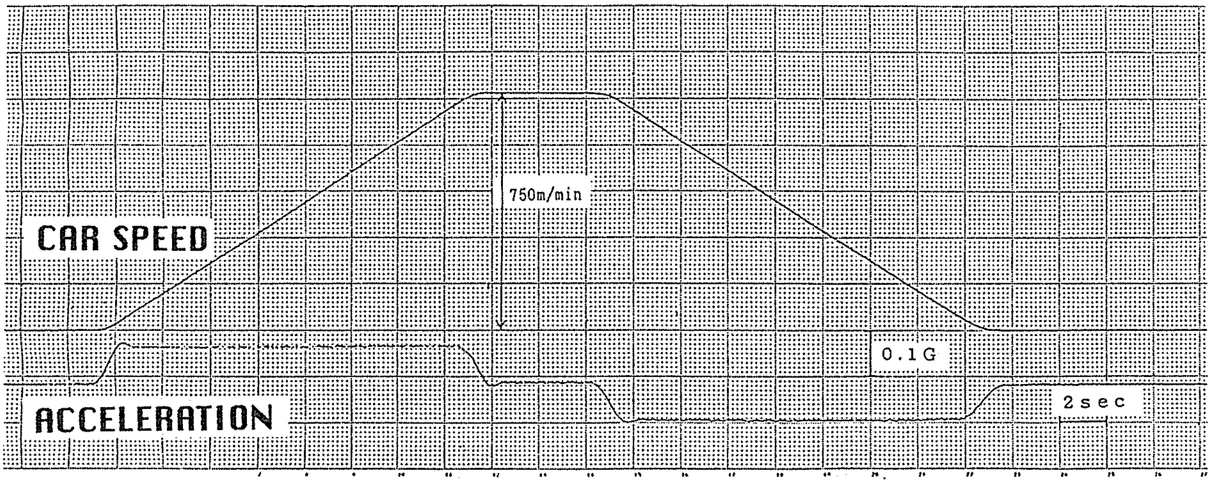

FIG. 4 CAR SPEED AND ACCELERATION PERFORMANCE AT FULL LOAD UP OPERATION

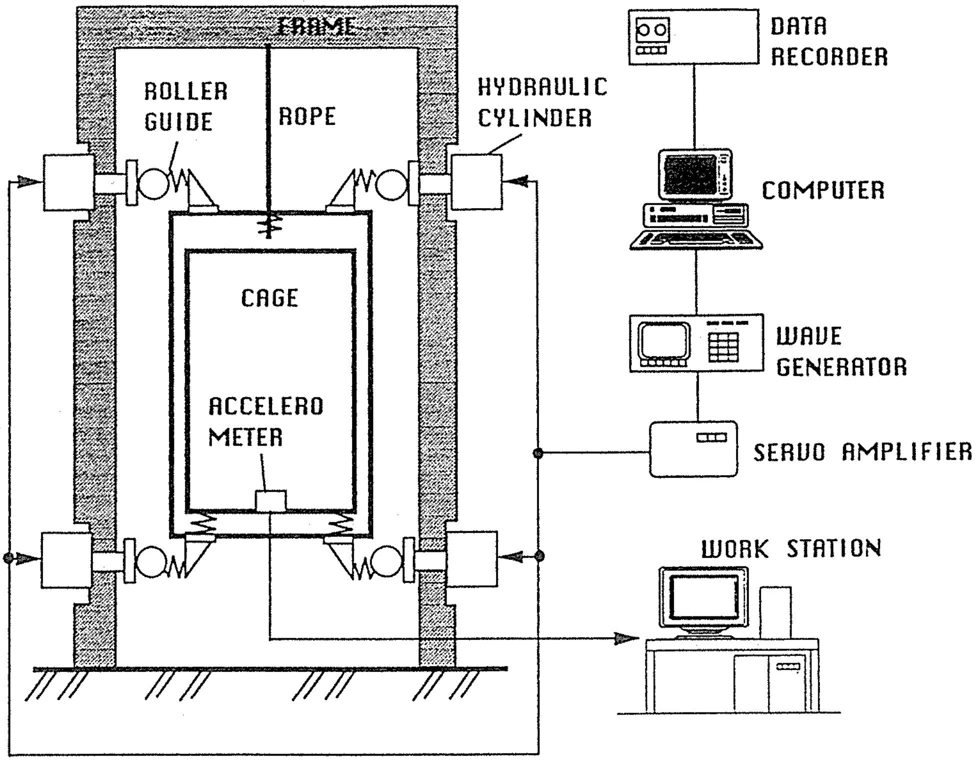

FIG.5 CONFIGURATION OF VIBRATION TEST DEVICE

4.1 Guide Rails

Special guide rails, each weighing 37kg/m (30kg/m for the elevators travelling at 600m/min. for SUNSHINE 60) are used in order to reduce the deflection caused by the horizontal reaction force. Each rail was closely checked for precision and for determination of the joining order. A number representing the joining order was marked on each rail so that they could be properly assembled at the customer's site.

4.2 Improvements in the Car Vibration Characteristic

For the research of improving car vibration characteristics, we performed simulations using a vibration test device.

A finite element program, "NASTRAN", was used to simulate the model characteristics of a car travelling at 750m/min. with a rated load of 1600kg. The simulation results indicated that the horizontal vibration could be reduced by changing the damping constant of the roller guide. Fig. 2-D shows the external view of the oil dampers for the roller guide which was developed according to the optimum damping constant obtained by simulation. We performed an experiment by the "vibration test device" using a car equipped with the newly developed oil dampers.

The configuration of vibration test device is shown in Fig. 5. As shown in the figure, an actual car is hung from a frame with ropes and hydraulic cylinders vibrate the car roller guides horizontally. The cylinders are servo-controlled and are driven by inputting any type of waveform generated by a waveform generator. In addition, the cylinders may also be driven using waveforms measured from actual curving guide rails (recorded prior to this simulation) and also by any type of speed waveform. From the application of this device and the software to analyze the simulation results, it has become possible to obtain information such as car natural frequency and vibration mode. We performed experiments using roller guides with the newly developed oil dampers and also with conventional friction dampers in order to compare the difference in their performance. The experiment result showed that the application of oil dampers could reduced the vibration by 20%.

4.3 Measurement of Horizontal Vibration During Actual Car Operation

Fig. 6 shows the vibration measured at the car platform while travelling at 750m/min. The vibrations in both the forward/backward and right/left directions have been reduced and a comfortable elevator ride was achieved. This measurement proves that the aforementioned countermeasure contributes to the reduction of the horizontal vibration. The degree of vibration varies depending on the adjustment of oil dampers. As the simulation results indicated, vibration will increase when the damping constant is excessively large or small, i.e., the vibration can be reduced only by an optimum damping constant. Fig. 6 shows the result with the oil dampers set to the optimum damping constant.

5. TECHNOLOGIES FOR REDUCING NOISE INSIDE THE CAR

There are two types of noise involved with elevator operation; mechanical noise and aerodynamic noise. Mechanical noise occurs by the contact between an elevator and the guide rails. 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 wind velocity to the powers of 5 through to 6 around the car. Due to this fact, aerodynamic noise is usually larger than mechanical noise with super-high-speed elevators which travels at 750m/min., therefore it is important to reduce the aerodynamic noise in order to achieve a comfortable elevator ride.

5.1 Solution for Aerodynamic Noise

As a car moves, the air flow around the car separates from the car surface at either the top

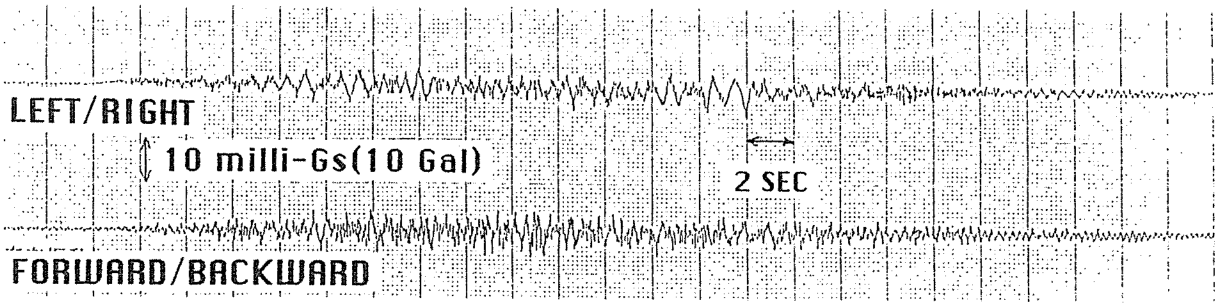

FIG.6 VIBRATION PERFORMANCE

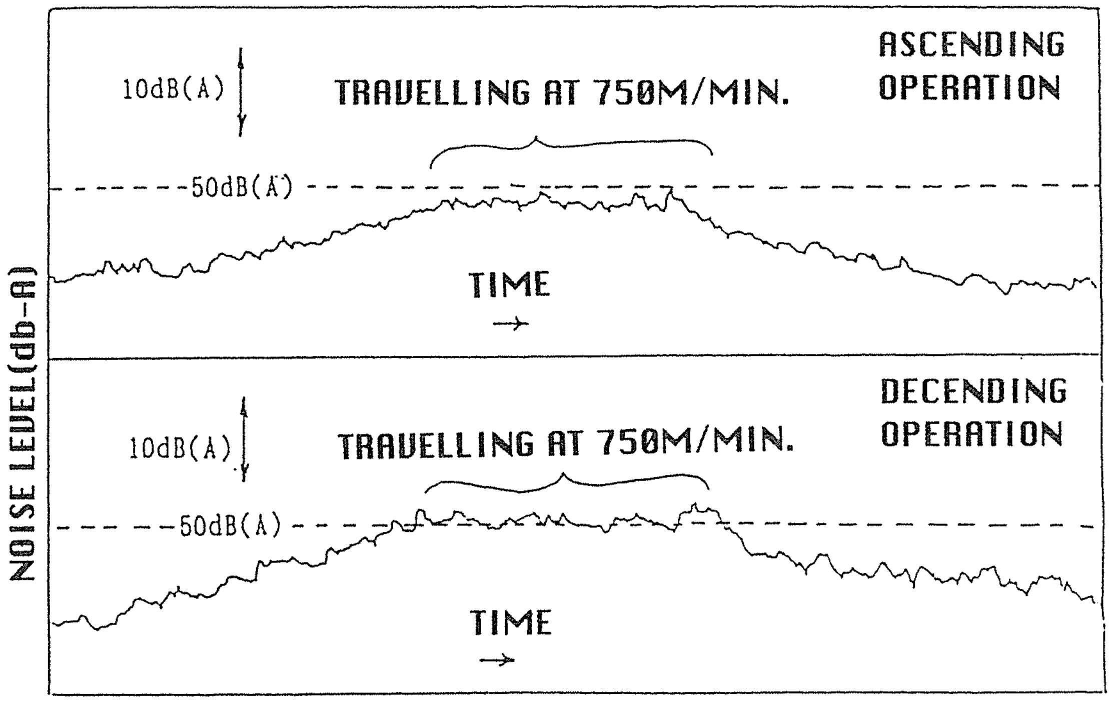

FIG.7 NOISE LEVEL INSIDE THE CAR AT 750M/MIN.

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. To solve this noise problem, streamlined covers may be mounted on both the top and bottom faces of the car in order to effectively reduce the air flow separation. Streamlined covers are actually mounted on the elevators delivered to the SUNSHINE 60, thus the effectiveness of the covers in noise reduction have already been confirmed.

Further improvements of streamlined covers, however, were required for the elevators delivered to The LANDMARK TOWER Yokohama in order to achieve the desired noise reduction. We performed "wind tunnel experiment" using a 1:12.5-scale miniature elevator with removable streamlined covers mounted to it. Fig. 2-E shows the streamlined covers designed according to the results from the experiment analysis.

5.2 Noise Insulation

The measurement with the conventional high-speed elevators indicates that 60% of the noise enters a car through the clearance around the doors, 15 to 20% through the surrounding walls, about 15% through the ceiling and 5 to 10% through the car platform. The aerodynamic noise is more likely to enter into the car through the doors due to the clearance between the doors and the cab made for the door open/close structure. As a solution, we applied sound insulation shields, as shown in Fig. 2-F, which seals the clearance when the doors are closed. Noise is also caused by the car walls as they are vibrated by the air pressure fluctuation. In order to reduce this noise, we developed the double-wall structure by separating the inner walls from outer walls and succeeded in reducing the noise by 45%.

5.3 Reduction of Noise Reverberation

The noise which enters into the car increases due to the reverberation occurring inside the car. This noise can be reduced by an air gap on the back side of sound absorbing porous material. We developed the method, as shown in Fig. 2-G, in which a carpet made of sound absorbing porous material is placed on top of punching metal (plate with punched holes) providing an air gap underneath the punching metal.

We performed an experiment in order to obtain the optimum sound absorbing effect using several carpets of varying pile length and varying surface conditions and also by changing the depth of the air gap. We selected the carpet type and the depth of the air gap according to the experimental results and performed further experiment using a model car made to the actual car size. The result showed a noise reduction of 40% and it was found that the noise of the 750m/min. elevators for the LANDMARK TOWER could be reduced by 5db (A) in comparison with that of conventional elevators by applying the above mentioned structure.

5.4 Measurement of Noise Using Actual Cars

In addition to the aforementioned double-wall structure, streamlined covers and the sound absorbing technique (double-floor structure), we improved the noise insulation effect of the doors. As a result, we succeeded in reducing the noise inside the car by 50db (A) during ascending operation and by 52db (A) during descending operation (see Fig. 7). This noise level is within the range of that for conventional high-speed elevators, and amazingly low for elevators travelling at 750m/min.

6. CONCLUSION

The outline of the system of the world's fastest elevators delivered to The LANDMARK TOWER Yokohama. was introduced in this paper. This building was opened to the public on July 16 of this year and many people have enjoyed the spectacular views from the top of the building.

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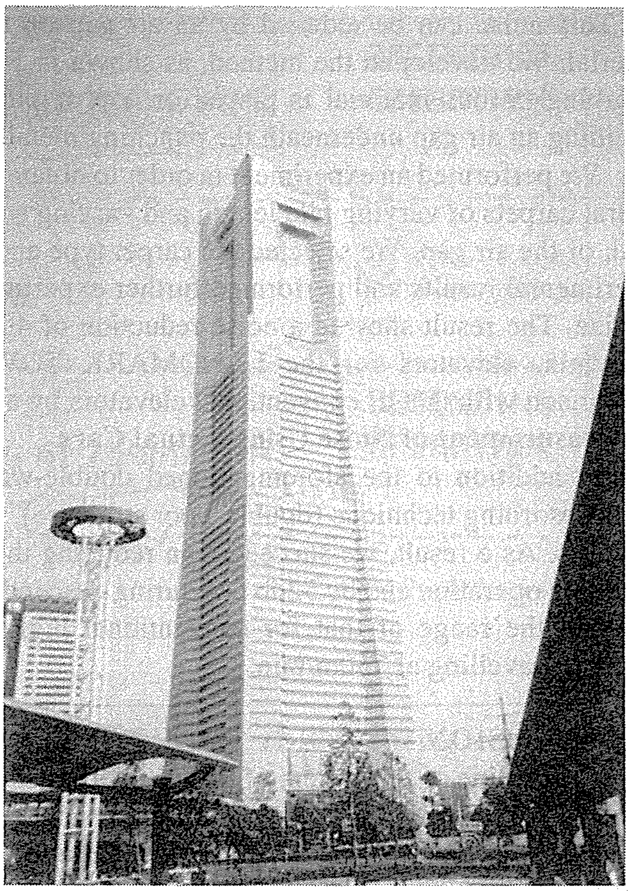

FIG.1 THE LANDMARK TOWER YOKOHAMA