Safety Devices for 750m/min.(12.5m/sec.) Elevators

K. Sugita, Y. Sugiyama, E. Watanabe & H. Kamaike
Mitsubishi Electric Corporation, Inazawa Works, Inazawa, Japan

ABSTRACT

We, Mitsubishi Electric Corp., have developed the safety devices which absorb the increased kinetic energy and stop the elevators without fail in an emergency. Needless to say, the development of the safety devices is of prime importance to assure the safety of the world's fastest passenger elevators which travel at speeds of 750m/min. For the development of highly advanced safety devices, we used computers to simulate the characteristics of the safety devices, such as the temperature rising characteristics of the safety gear shoes, and conducted several tests such as the test of "duration of devices against impact" and "braking performance" in free-fall conditions. We also simulated the movements of the devices used in the elevator system upon the activation of the safety devices in order to confirm the safety of the elevator system.

1. INTRODUCTION

The trend toward constructing higher buildings has caused the increasing demand for high-speed elevators. In order to meet this demand, we have developed super-high-speed elevators, and recently delivered the world's fastest passenger elevators travelling at 750m/min. to The LANDMARK TOWER Yokohama, Japan's tallest building which was completed this year.

It is important to provide each elevator with the safety devices which absorb the increased kinetic energy and stop the elevator without fail, since the kinetic energy of an elevator car increases dramatically when it travels at super-high-speed.

It is also important to develop new technologies for evaluating the products using specific kinds of devices, such as a computerized simulator, because evaluating and testing an elevator in actual travelling operation requires a lot of manpower and time. The outline of the development of the safety gears and the oil buffers, together with the designing and evaluation technologies, are introduced hereafter in this paper.

2. SAFETY GEARS

2.1 Specifications of Safety Gears and Technical Requirements

The differences in the specifications between the safety gear for The LANDMARK TOWER Yokohama and that for the SUNSHINE 60 Bldg. in Tokyo are shown in Table 1. The SUNSHINE 60 Bldg. incorporates the elevators travelling at the previous world's fastest speed of 600m/min.

The operating speed of the safety gears for the LANDMARK TOWER is 937m/min., which is 1.25 times that of the SUNSHINE 60 Bldg., and the stop energy is approximately twice as large because the maximum allowable mass of the LANDMARK TOWER elevators is larger than that of conventional high-speed elevators. These facts indicated that the conventional shoes made of cast iron, etc. would wear out when the shoes' operating speed reaches 800m/min. because of the temperature elevation on the shoes' rubbing surfaces, resulting in the failure of stopping the elevator accurately. For this reason, it became necessary to study the characteristics of temperature elevation, and to develop a material which would withstand the high temperature and assure the desired braking performance.

Item		Yokohama LANDMARK TOWER	SUNSHINE 60 (Tokyo)
Rated Speed	(m/min.)	750	600
Capacity	(Kg)	1600	1600
Travelling	(m)	267	222
Max. Operation Speed	(m/min.)	937	750
Max. Allowable Mass	(Kg)	13000	9500
Braking Distance	(m)	12.5 to 36.6	8.0 to 23.0

Table 1 Specifications of Safety Gears

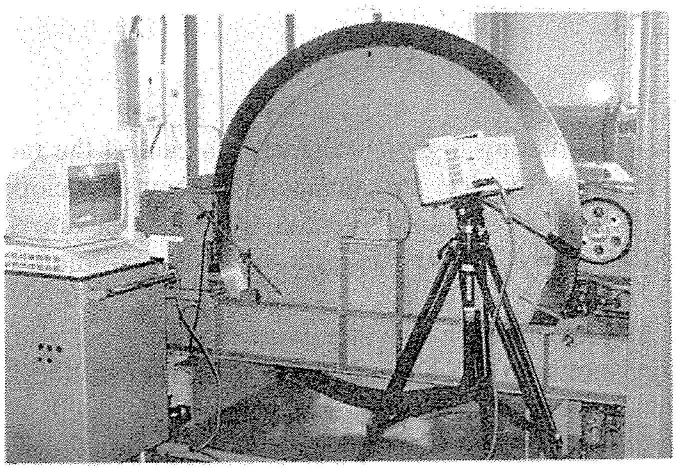

Fig. 1 External View of Disk Test Device

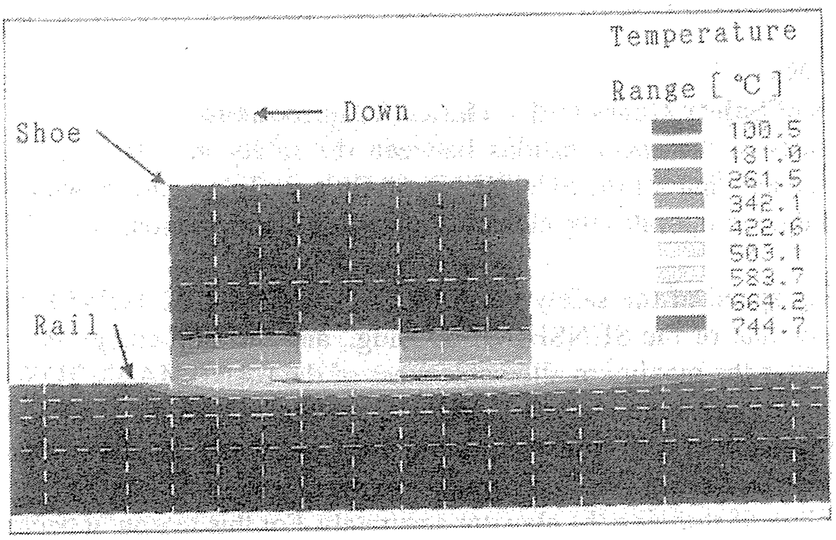

Fig. 2 Heat Distribution on Shoes' Rubbing Surface

2.2 Temperature of Safety Shoes' Rubbing Surface

We used the 3-dimensional FEM (finite element method) program, "ANSYS", to analyze the temperature characteristics of the shoes' rubbing surface. The heat is distributed symmetrically about the center in the shoe's longitudinal direction. Therefore, we used a 1/4 scale model shoe for the simulation. We simulated the movement of the shoe from the moment of shoe's activation until its complete stop by changing the heat conductivity on the shoe's rubbing surface.

We used a disk test device for the equivalent test, which is shown in Fig. 1, in order to confirm whether the conditions for the heat analysis (analysis accuracy and the consistency of data elements such as the constants we had applied in the simulations) were appropriate. In the equivalent test, we rotated the disk, activated the shoe at the pre-determined speed, and then analyzed the temperature on the shoe's side surfaces and of the rail using an infrared ray thermometer. By these tests, we obtained more information about the shoe's temperature elevation characteristics with respect to time.

The sectional view of the shoe is given in Fig. 2. The distribution of the heat generated when the shoe has operated at a speed of 937m/min. is shown.

The analysis results indicated the following facts.

(1) Only the temperature on the rubbing surface, as viewed in section, rises. The area of highest heat density is displaced a short distance from the center of the shoe, in the opposite direction to that of the shoe's motion.

(2) When the safety gear has operated, the temperature of the shoe's rubbing surface reaches its peak quickly, and then slowly falls. The temperature in our test reached its peak in 0.2 sec.

(3) The temperature exceeds 750°C. Shoes made of iron will not achieve the desired braking function, since the temperature is over the transformation point A_1 of iron.

Based on this information, we developed shoes which could withstand high temperatures and achieve a constant braking performance.

2.3 Braking Test of Safety Gears

2.3.1 Test for Selecting Shoes Material

It is difficult to perform the tests efficiently using equipment equivalent to the actual elevator set-up. For this reason, we used the disk test device for the 1st "material selection test", and then performed free-fall tests using a 1/10 scale model car for the 2nd "material selection test". The "1/10 scale model car free-fall test device" used for the 2nd test is shown in Fig. 3. After these two tests, we confirmed the performance of the selected material by a test device which is equivalent to the actual elevator set-up.

As well as cast iron, we tested several materials which have high heat-resistance and hardness. The pressing force and rubbing area of the shoes was calculated prior to the tests in order to simulate the same conditions as would be present in the LANDMARK TOWER, i.e., joule/unit area and joule/unit time. The force and area was applied to the various material types giving the wear thickness (the amount of material lost by the friction) results of Table 2, at an operating speed of 937m/min. In this table, you can compare the wear thickness of all the materials with that of cast iron which is set to 100. The wear thickness of special ceramic and special heat resistant high alloy is extremely small in comparison with that of cast iron. This result indicated that the shoes made of special ceramic and special heat resistant high alloy could achieve the desired braking performance even after the temperature has exceeded 750°C. We tested these materials using the 1/10 scale model car free-fall test device. In this test, we checked how the friction coefficient would fluctuate while the shoes were in braking

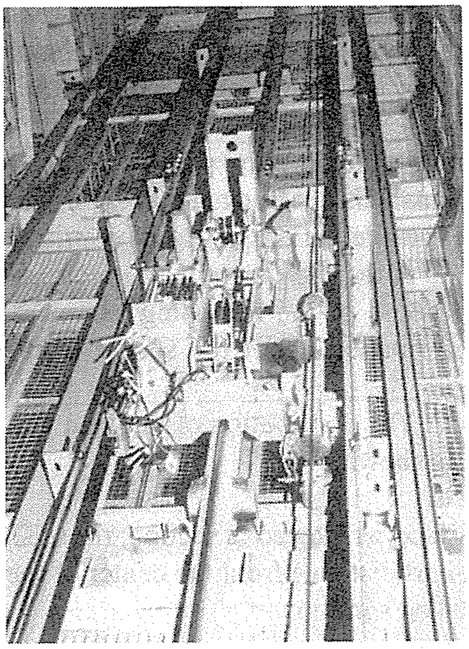

Fig. 3 External View of 1/10 Scale Model Car Free-Fall Test Device

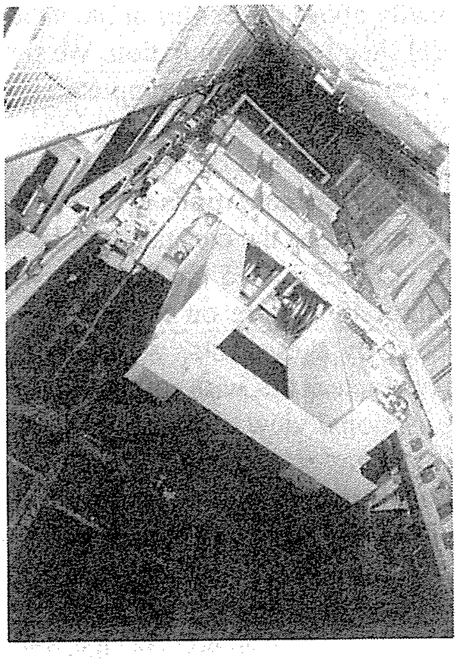

Fig. 4 External View of Free-Fall Test Device Equivalent to Actual Elevator Set-Up

Shoe Materials	Shoe Wear Thickness
Cast Iron	100
Special Cast Iron	110
Copper Sintered Alloy	75
Special Copper Sintered Alloy	129
Special Heat Resistant High Alloy	2
Special Ceramic	0.4

Table 2 Wear Thickness of Shoes

[Note] The value for cast iron is set to "100" as a basis of comparison for the other values.

operation and how the surface condition of the rails (which varies due to rust, etc.) would affect the fluctuation.

According to the results obtained from these tests, we selected a special ceramic for the shoes of super-high-speed elevators, since special ceramic wears out the least and has the smallest fluctuation in the friction coefficient. In addition, in order to check the strength of special ceramic, we performed an impact resistance test and confirmed that the special ceramic we had selected had the desired resistance against impact.

2.3.2 Free-Fall Test

Fig. 4 shows the external view of the "free-fall test device" which was used to test the safety gears developed for the LANDMARK TOWER. We mainly checked 1) the braking distance and deceleration (Fig. 6), 2) the fluctuation in the friction coefficient (Fig. 7), and 3) the temperature rise of the shoes (Fig. 8) in order to confirm the reliability of the shoes which is made of special ceramic. The configuration of the test device is shown in Fig. 5. On this device, we mounted the counterweight which was equal in weight to the maximum allowable mass (including the weight of the safety gear), and also mounted the safety gear on the bottom of the counterweight frame.We released the shackle to drop the frame in a free-fall condition. In order to measure the temperature of the shoes, we put the chromel-alumel thermocouples inside the shoes.

As shown in Fig. 6, the shoes started braking when the speed has reached 937m/min. and brought the frame to a complete stop in 16.5m, achieving a smooth braking deceleration. This result satisfies the requirements of the JIS (Japanese Industrial Standard), ANSI (American National Standard Institute) and EN (European Standards). The ceramic shoes showed little signs of wear on repeating the same test and showed a consistent breaking performance.

The average friction coefficient of the shoes in the braking operation and the corresponding operation speed of the safety gear are given in Fig. 7. The figure shows that the friction coefficient varies depending on the safety gear operating speed but is not affected by the pressing force. It also shows that the friction coefficient at a speed exceeding 937m/min. is stable. These results indicated that the safety gear made of special ceramic could achieve the braking performance required for the elevators of the LANDMARK TOWER.

In Fig. 8, the shoes' temperature exceeding 1,000°C can be seen. Special ceramic we selected has high strength against elevated temperature and was the best selection to be used for the shoes of safety gears.

By the simulations and the tests explained in this section, we were able to establish the technologies required to achieve reliable braking performance for super-high-speed elevators.

3. OIL BUFFERS

The specifications of the oil buffer developed for the LANDMARK TOWER, together with those of the oil buffer for the SUNSHINE 60 Bldg., are shown in Table 3. In comparison, the buffer for the LANDMARK TOWER has about 1.5 times the stroke of that of the SUNSHINE 60, and about twice the impact absorbing energy value. The design of orifices is crucial for the buffer to absorb the shock of the elevator car and to achieve the deceleration characteristics designated in elevator codes. In order to achieve the desired buffers' functions, the speed and load conditions were taken into consideration when designing the orifices, and the design was checked by simulating the deceleration characteristics using the Mitsubishi-made program "BACS". Furthermore, we adopted special high-tensile strength steel for the plunger's return-spring since the size of the return-spring would have been extremely large if it was made of a conventional material, due to the fact that the stroke was as large as 4,000mm. We also applied the designing and processing technologies which had previously been

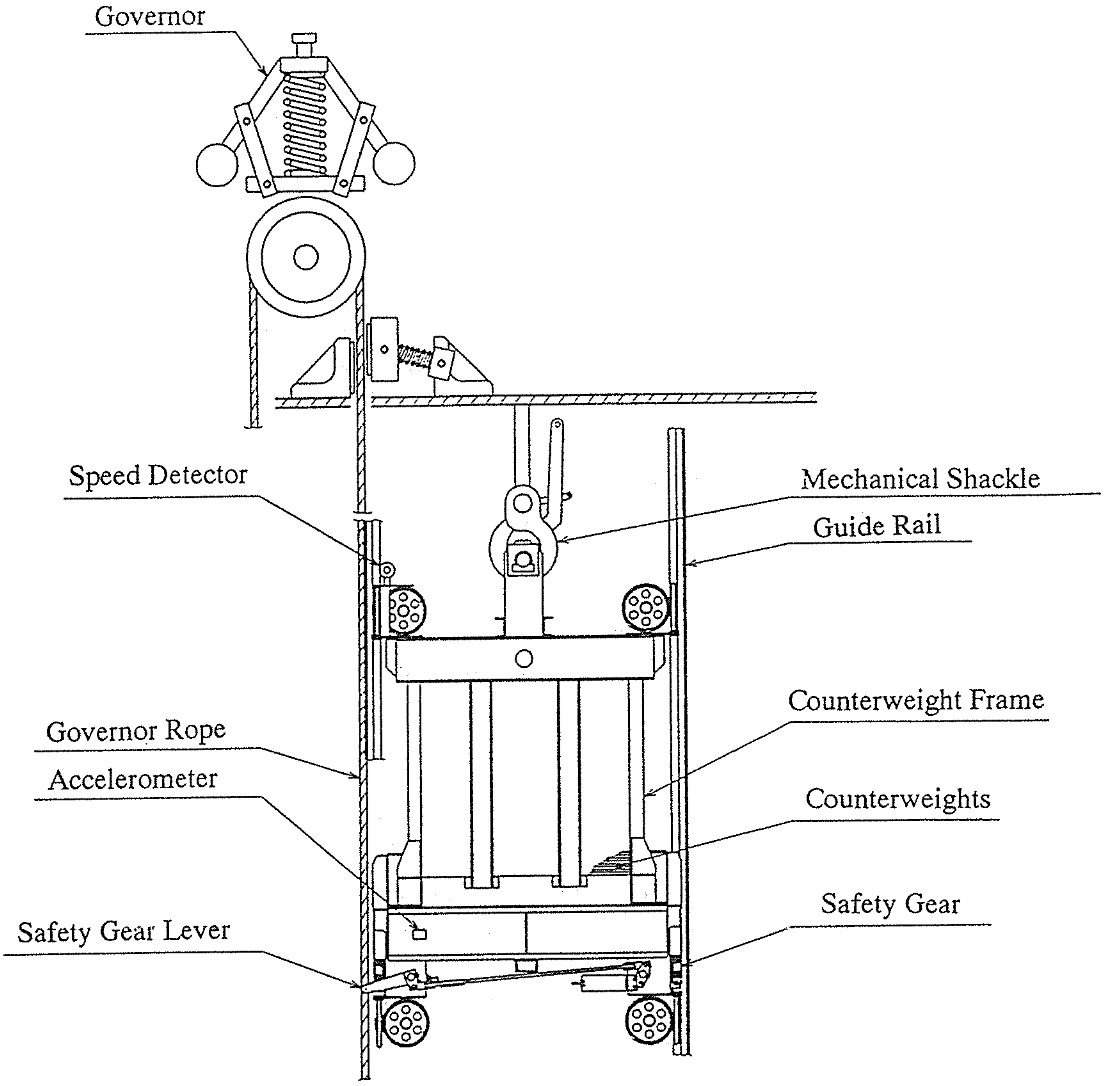

Fig. 5 Configuration of Safety Gear Test Device

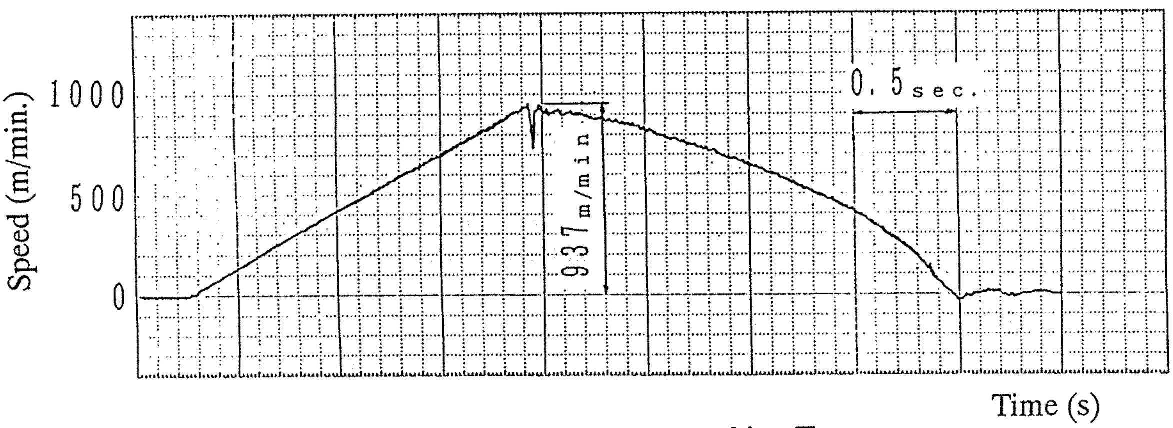

Fig. 6 Result of Safety Gear Braking Test

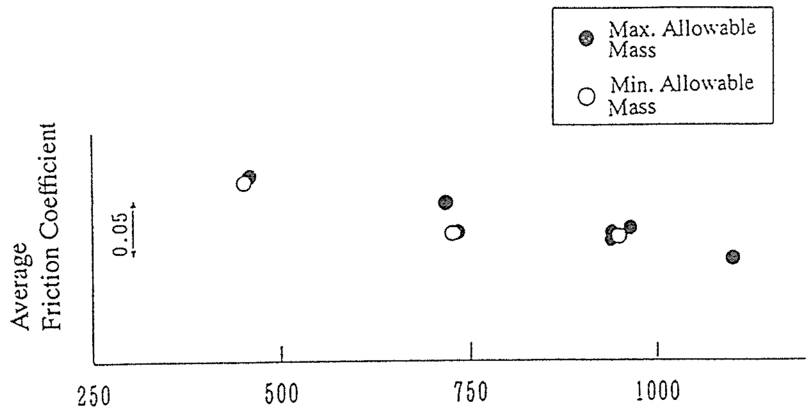

Fig. 7 Average Friction Coefficient of Special Ceramic Shoes

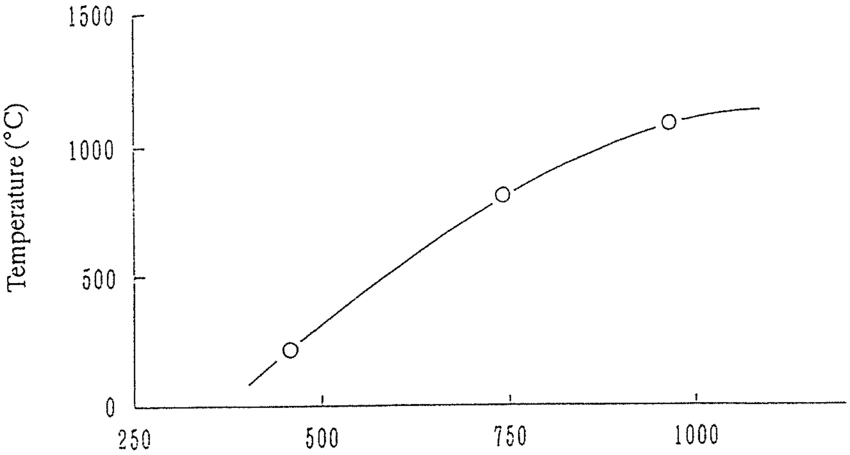

Fig. 8 Temperature on Shoes' Rubbing Surface

Item	Yokohama LANDMARK TOWER	SUNSHINE 60 (Tokyo)
Stroke (mm)	4000	2800
Max. Collision Speed (m/min.)	530	444
Max. Allowable Mass (Kg)	10000	75000
Min. Allowable Mass (Kg)	5000	2000
Deceleration Characteristics Average Maximum	9.81 m/s^2 or less Time exceeding 24.54 m/s^2 is 0.04 sec. or less	
Plunger Return Time	90 sec. or less	

Table 3 Specifications of Oil Buffers

developed for the long-stroke hydraulic jacks of hydraulic elevators.

We tested the deceleration characteristics of the buffer using the counterweight frame shown in Fig. 5. We dropped the frame in a free-fall condition from the designated height to achieve the maximum striking impact and measured the deceleration of the frame. In Fig. 9, you can compare the simulation result and experimental result. The frame struck the buffer at a speed of 530m/min. The maximum deceleration was $20m/s^2$ and the average was $4.3m/s^2$. The experimental data reflected the results of the simulations, and satisfied the requirements of ANSI and EN. Thus, the oil buffers which would assure the safety for super-high-speed elevators of large load capacity were realized.

4. MOVEMENTS OF ELEVATOR SYSTEM DEVICES UPON THE ACTIVATION OF SAFETY DEVICES

Besides the fact that the passenger elevators for the LANDMARK TOWER travel at the world's fastest speeds, the travelling of the LANDMARK TOWER is very long, measuring 267m. Due to this long travelling, it is significant to study the movements of the car and the counterweight upon the activation of the safety devices, which are linked by 300m-long traction ropes. We simulated the movements of the car, counterweight, and other devices in the elevator system using the "BACS" program.

Fig. 10 shows the simulated movements of the car and the counterweight upon the activation of safety gear, and Fig. 11 shows the simulated movements of the car travelling beyond the limit of the upper terminal floor and the counterweight striking the oil buffer. In addition, we simulated the movements of the other devices such as the governor ropes and the compensating rope apparatus. The affect of an oscillatory deceleration which could occur by the car's upward overtravel at the upper terminal floor was one of the major concerns, but on simulation, this was proved to be unfounded. Thus, we confirmed that the elevator system would assure the safety upon the activation of the safety devices.

5. CONCLUSION

The outline of the newly developed safety devices, the evaluation methods and the results were introduced in this paper. In several simulations and experiments, the reliability of the newly developed safety devices was proven. Thus, we were able to break the previous world's fastest record of passenger elevators leaving a remarkable record in elevator history, and were able to establish the technologies of safety devices needed for super-high-speed elevators. We are dedicated to providing continual research and development to realize the elevators which will meet the future market demands.

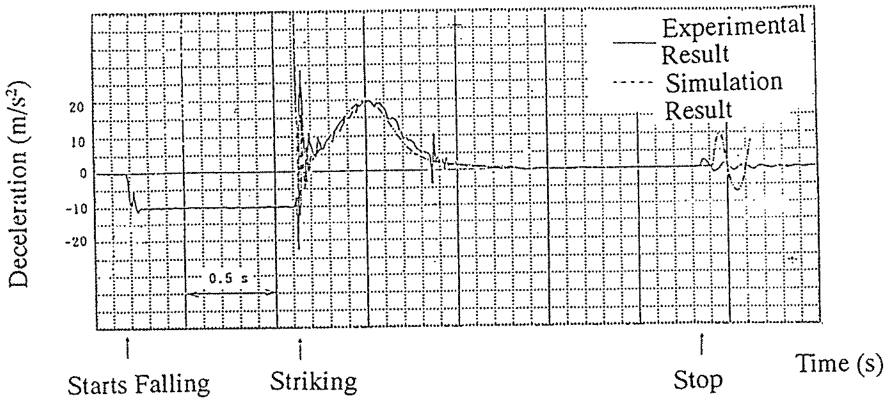

Fig. 9 Experimental Result and Simulation Result of Oil Buffer

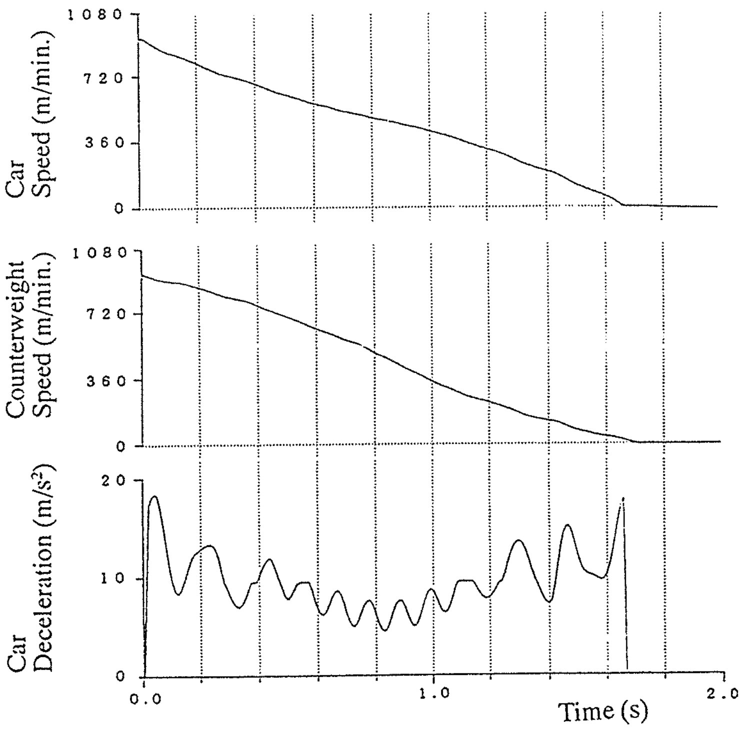

Fig. 10 Simulation Results of Devices' Movements in Elevator System (upon safety gear's activation)

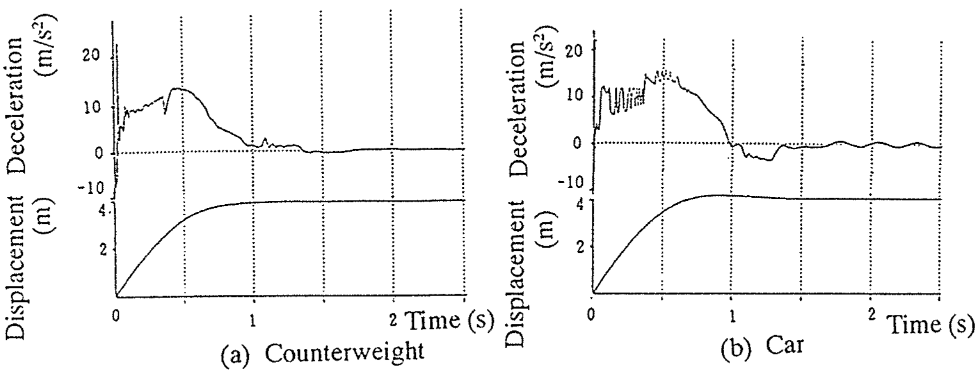

Fig. 11 Simulation Results of Devices' Movements in Elevator System (upon oil buffer's striking)

Author Biographical Details:

Kazuhiko Sugita
Born 1956 in Okayama, Japan.
Mechanical Engineering Degree from Tokyo Institute of Technology in 1979.
Joined Mitsubishi Electric Corp. (Japan) in 1979.
Presently Assistant Manager of Elevator Mechanical Development Section of Inazawa Works, Mitsubishi Electric Corp., Japan.

Yoshiki Sugiyama
Born 1952 in Tokyo, Japan.
Mechanical Engineering Degree from Waseda University in 1975.
Joined Mitsubishi Electric Corp. (Japan) in 1975.
Presently Manager of Elevator Mechanical Development Section of Inazawa Works, Mitsubishi Electric Corp., Japan.

Eiki Watanabe
Born 1941 in Osaka, Japan.
Electrical Engineering Degree from Osaka University in 1963.
Joined Mitsubishi Electric Corporation, Japan, in 1963.
Presently Manager of Development Department of Inazawa Works, Mitsubishi Electric Corporation, Japan.

Hiroshi Kamaike
Born 1944 in Osaka, Japan.
The B.E. Degree in Automatic Control Engineering from Osaka University in 1966.
Joined Mitsubishi Electric Corporation, Japan, in 1966.
Presently Manager of Elevator & Escalator Engineering Department of Inazawa Works, Mitsubishi Electric Corporation, Japan.