Safety Gear for Ultra-High Speed Elevator

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ABSTRACT

Toshiba has developed a safety gear for elevators running at the rated speed of 1,000m/min. Safety gears for elevators running in the speed class of 1,000m/min use a friction material made of a fiber-reinforced compound material which has silicon nitride as a main ingredient to prevent deterioration of the friction material due to heat generated by friction. The friction coefficient is further enhanced by providing grooves on surfaces of the friction material and by other means. A friction coefficient 50% higher than those of conventional metallic friction materials has been accomplished.

Basic performance of ceramic friction materials was studied and a ceramic material was selected. Problems special to safety gears were studied in a miniature test using a safety gear for small elevators. A drop test was conducted using a drop test apparatus equivalent to an actual cage.

1. Introduction

A large number of high-rise buildings have been built recently and elevators with large capacities and high travels running at a high speed to suit these buildings have been in demand.

There are many challenges to build elevators running at an ultra-high speed. The safety gear is one of the most important components of the elevator. The safety gear mechanically prevents dropping of the cage by generating a friction force between the guide rails and the safety gear when speed increases to malfunction and cannot control.

Cast iron, sintered alloys or other materials have been used as the friction material of the safety gear. When operated at a high speed in the class of 1,000m/minute, the temperature on the friction sliding surfaces surpasses the melting points of these metals and this is feared to cause problems such as lowering of the friction coefficient and seizure with the guide rails if a conventional friction material is used.

This paper discusses the friction material of the safety gear recently developed for elevators running at the rated speed of 1,000m/min and a drop test of the safety gear.

2. Challenges for 1,000m/min-Class Safety Gear

The energy which the safety gear must brake (absorption energy) is the total sum of the kinetic energy of the cage, passengers or cargo, ropes and other items and potential energy which the masses of them lose after the safety gear is activated and stops by braking.

The ropes to drive the elevator become thick higher the buildings are. Thus, the mass which the safety gear must brake will increase longer the travel is as buildings become taller even though the loaded mass is the same. The mass which the safety gear must brake will be as much as 22,000kg with a safety gear at the rated speed of the 1,000m/min-class, which is greatly different from that at the rated speed of 600m/min. (See Table 1.)

The absorption energy of the safety gear rises to the second power as the rated speed increases, thus greatly increasing the burden to the safety gear.

Assuming that the average deceleration of the safety gear to be 0.6G, the absorption energy of the safety gear would be 13MJ. This energy is more than six times that of the safety gear for the rated speed of 600m/min developed by Toshiba. An increase in the size of the safety gear increases the burden to the safety gear itself and is not desirable. This problem is solved by increasing the absorption energy per unit area of the friction material while maintaining the same size as before.

The burden to the friction material is large as it is demanded to have absorption energy more than six times while the size is approximately the same size as before. The friction material of the safety gear is a specially important elemental technology.

Table 1 Comparison of Safety Gears at Rated Speeds of 1,000 and 600m/min

Rated Speed	1,000m/min	600m/min
Travel	600m	250m
Loaded Mass	2,000kg	2,000kg
Mass other than load*	20,000kg	8,000kg
Absorption Energy of Safety Gear	13MJ	2MJ

* "Mass other than load" means total sum of masses of the cage itself, compensating rope, etc.

3. Friction Material for the Safety Gear

The friction material for use in safety gears of the 1,000m/minute class is required to have the following performance:

1) Heat Resistance

Braking at a speed in the class of 1,000m/minute, the surface temperature of the friction material exceeds 1,000℃. The friction material is required to demonstrate a stable braking characteristic at such temperature.

2) Wear Resistance

Activating the safety device at 1,251m/min (safety gear operating speed at rated speed of 1,000m/min), the braking distance would be as much as 37m. Until the elevator stops, the friction material must continue to generate a stable braking force and fluctuations in the braking force by wear are not desirable.

3) Stable, High Friction Coefficient

The friction material normally generates a braking force by being pushed to the guide rails by springs or other devices. The push force has to be increased and large safety gears would be required if the friction coefficient of a friction material is low. For this reason, a higher friction coefficient is more advantageous.

4) Low Damage to Mating Material (Guide Rails)

When a safety gear actuates, the guide rails on which the safety gear slides are damaged. Damage to guide rails lowers the elevator riding comfort and damage to the mating material must be minimized.

Special ceramic friction materials (for rated speed of 750m/min)[1], special cast iron friction materials (for rated speed of 810m/min)[2] and other materials are used as friction materials for ultra-high speed elevators currently in operation. Ceramic materials were studied because they offered good resistance to heat and wear among the foregoing performance requirements.

4. Inertial Friction Test

An inertial friction test was conducted first to select a ceramic material.

In an inertial friction test, the disc shown in Fig. 1 is rotated to a certain speed and the friction material is pushed to the disc to stop disc revolutions (inertia). The test was conducted by setting the revolution speed during the test so that the peripheral speed of the friction material would become 1,251m/min (safety gear operating speed at rated speed of 1,000m/min) and energy consumed per unit area of the ceramic friction material by braking would equal that of a real elevator.

Tests with various kinds of ceramics showed that a compound material obtained by fiber-reinforcing a ceramic material which had silicon nitride as its main ingredient excelled in friction coefficient and resistance to shock.

Tests were made by varying the ceramics shape. A columnar ceramic shape with grooves cut in it was found to produce a friction material with a high friction coefficient.

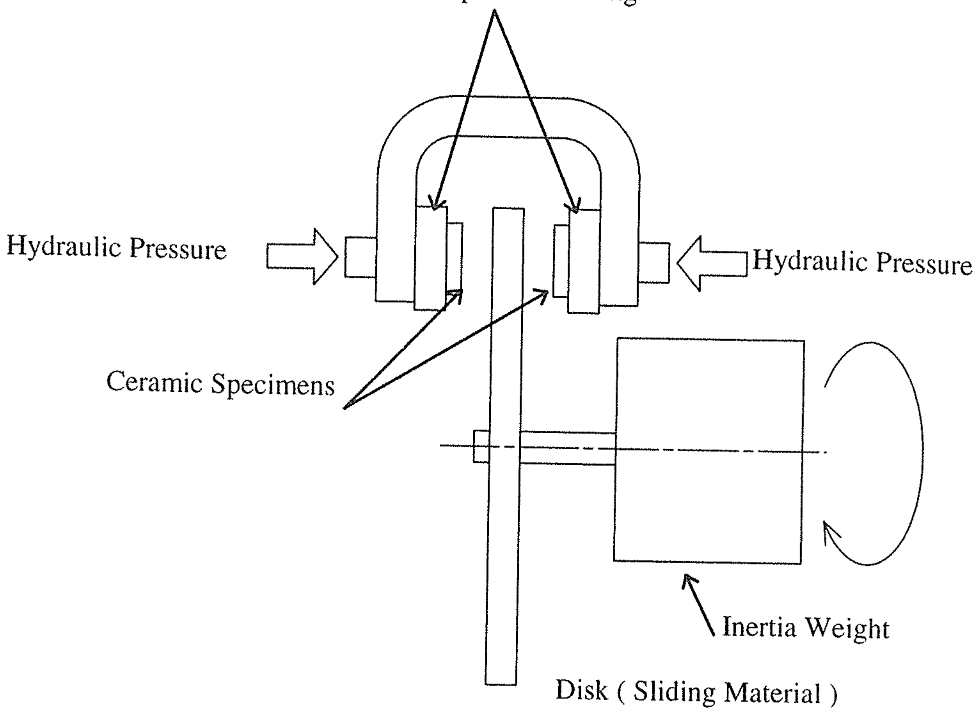

Fig. 1 Theory of Inertial Friction Test Apparatus

5. Drop Test by Miniature Test Apparatus

A drop test using a miniature test apparatus was conducted next before performing a drop test in a scale equal to that with an actual cage to check phenomena unique to the safety gear which could not be checked in laboratory tests.

The drop test by a miniature test apparatus placed an emphasis on the following items which could not be checked in inertial friction tests:

1) Impacts by Always-New Sliding Surfaces of Mating Material (Guide Rails)

Inertial friction tests use a disc-like mating material and the sliding surfaces are always the same surfaces. Actual safety gears slide on surfaces which are always new. Safety gears repetitively operated on the same sliding surface are known to vary the friction force (friction coefficient). For example, in EN81, new guide rails are used in every safety gear test. The impacts by this were checked before performing a drop test in an actual cage environment.

2) Impacts by Pushing Friction Material by Actual Safety Gear

Inertial friction tests are conducted using a friction material with a relatively small area and the pressure distribution of the friction material is averaged. However, sliding surfaces need to be large with actual safety gears so that the friction material contacts unevenly, probably affecting the braking power and damaging (cracking) the friction material itself.

Fig. 2 outlines the miniature test apparatus.

Table 2 gives the specifications of the actual machine, miniature test and inertial friction test.

The miniature test apparatus utilizes a test apparatus for inclined elevators. The drop dolly is accelerated by a catapult which uses a spring force and is stopped by braking it by a safety gear which uses a ceramic friction material.

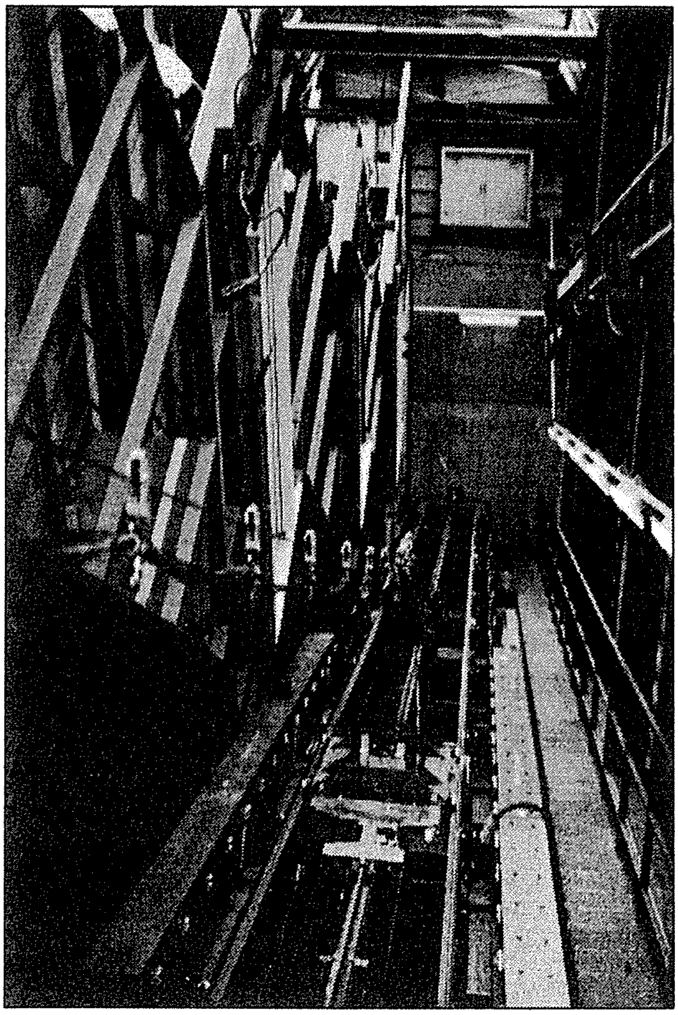

Fig. 2 Miniature Test Apparatus

Table 2 Specifications of Actual Machine Drop Test, Miniature Test and Inertial Friction Test

	Actual Machine	Miniature Test	Inertial Friction Test
Total Mass(kg)	22,700	200	1.5kgf · m · s^2
Speed at Start of Braking(m/min)	1,251	850	1,251
Braking Distance(m)	37	0.85	52
Absorption Energy (J)	13,171,000	20,900	290,000

The absorption energy was set to be 1/45 of real elevator in the inertial friction test so that the absorption energy per unit area of the friction material might become equal with a real elevator. In the miniature test, the test was conducted by setting the pressure of the sliding surfaces would become equal with a real elevator.

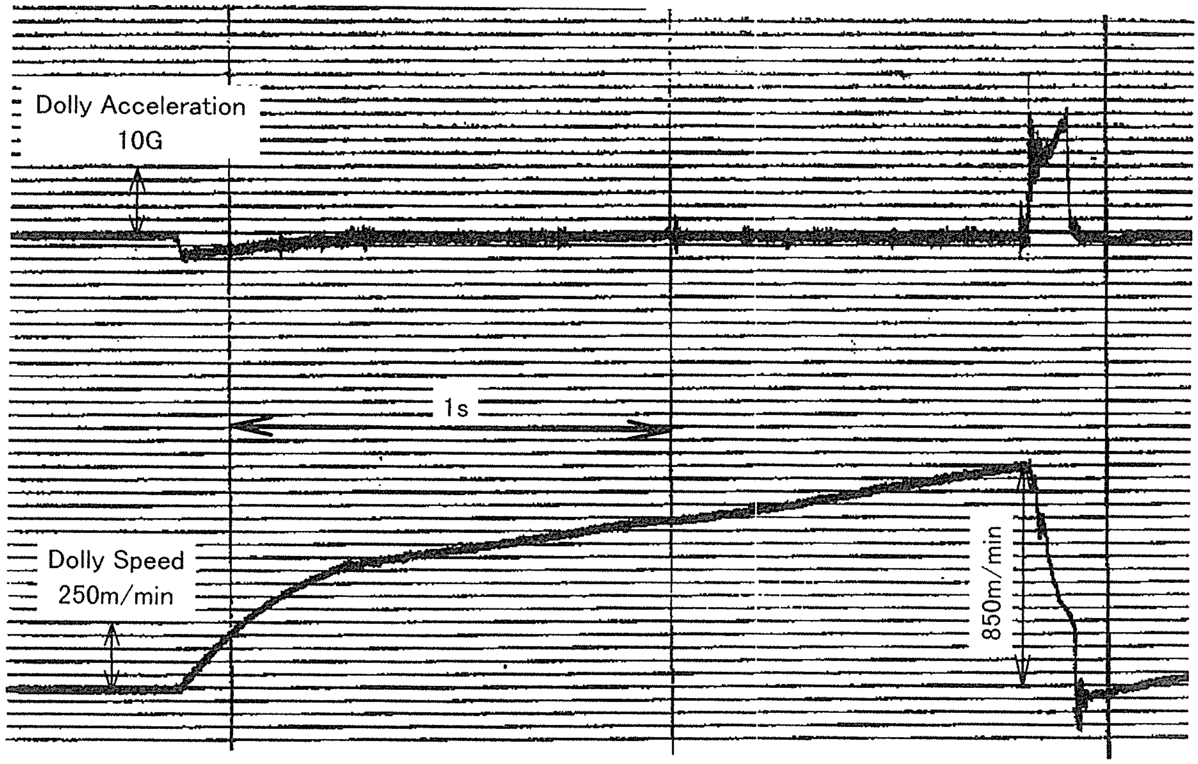

Fig. 3 Results of Drop Test by Miniature Test Apparatus

Fig. 3 shows an example of results of drop tests by the miniature test apparatus. The drop dolly accelerates up to 500m/min by the power of the spring. In addition, after the speed is increased up to about 850m/min according to gravity, the dolly is stopped by braking with the safety gear. Because the mass of the dolly is smaller than the braking force of the safety gear, an average deceleration is growing with about 12G.

Compared with the results of inertial friction tests, the friction coefficient deteriorated about 20%. It could be ascertained that some areas of the friction material were chipped if surface contact between the friction material and guide rails was uneven. The guide rail damage tended to deepen.

6. Drop Test with Actual Machine

After making a final selection of the friction material as outlined above, a drop test apparatus equivalent to an actual machine was conducted. Fig.4 , Fig.5 and Fig.6 show the friction material and safety gear used in the tests. The ceramic friction material has columnar shape as shown in Fig.4, and is set in the safety gear while set in a metallic plate as shown in Fig.5.

Table 3 outlines drop tests. The operation speed of the safety gear was decided 1,251m/min to rated speed of 1,000m/min in consideration of CEN, ASME etc. The safety gear is dropped 22m in a free form and is stopped by braking about 37m. If the safety gear does not work well by any chance, the fall speed reaches nearly 2,000m/min and is very dangerous. For this reason, backup braking devices are installed in the bottom of the hoistway.

Fig. 7 outlines the drop test apparatus. The channels for backup braking devices are set up on guide rails, and the braking force is generated between the channels and the backup braking devices installed on the cage frame.

Fig. 8 shows an example of drop test results. The cage reached 1,251m/min and is stopped by braking at an average deceleration of 0.80G and with the braking distance of 27.7m.

The friction material hardly showed wear and can be used repetitively. The damage to the guide rails was negligible and presents no problems in actual use.

Table 3 Summary of Drop Test at Rated Speed of 1,000m/min

Rated Speed	1,000m/min
Maximum Mass	22,700kg
Safety Gear Operating Speed	1,251m/min
Free Drop Distance	22.154m
Braking Distance	36.923m (Deceleration 0.6G)
Backup Braking Distance	Max. 50m

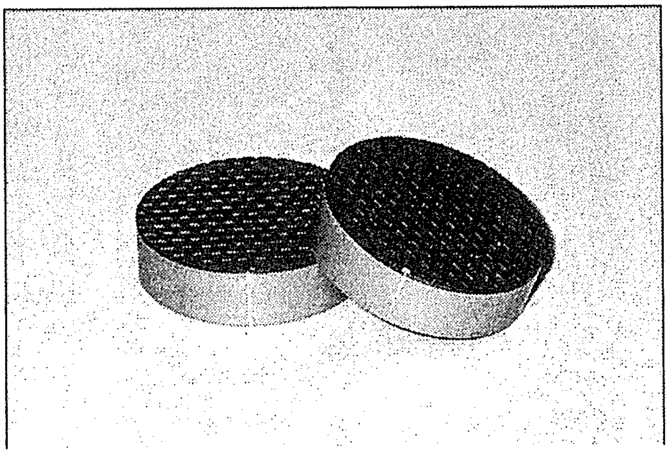

Fig. 4 Ceramic Friction Material Pieces

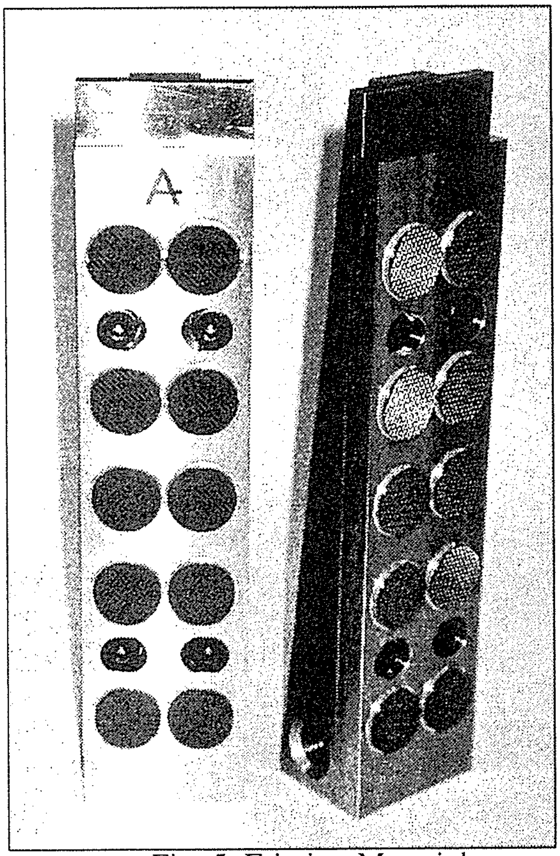

Fig. 5 Friction Material
(Set in a Metallic Plate)

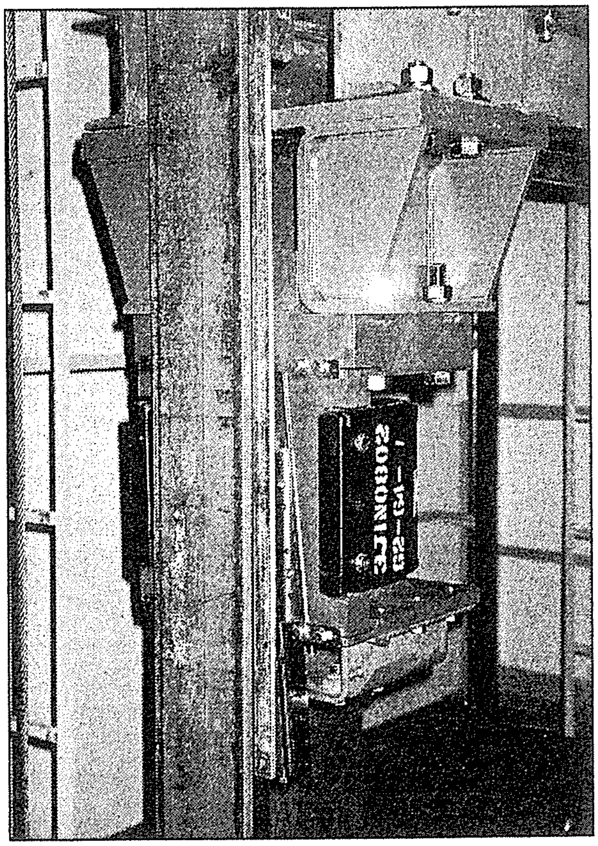

Fig. 6 Safety Gear for Rated Speed of
1,000m/min

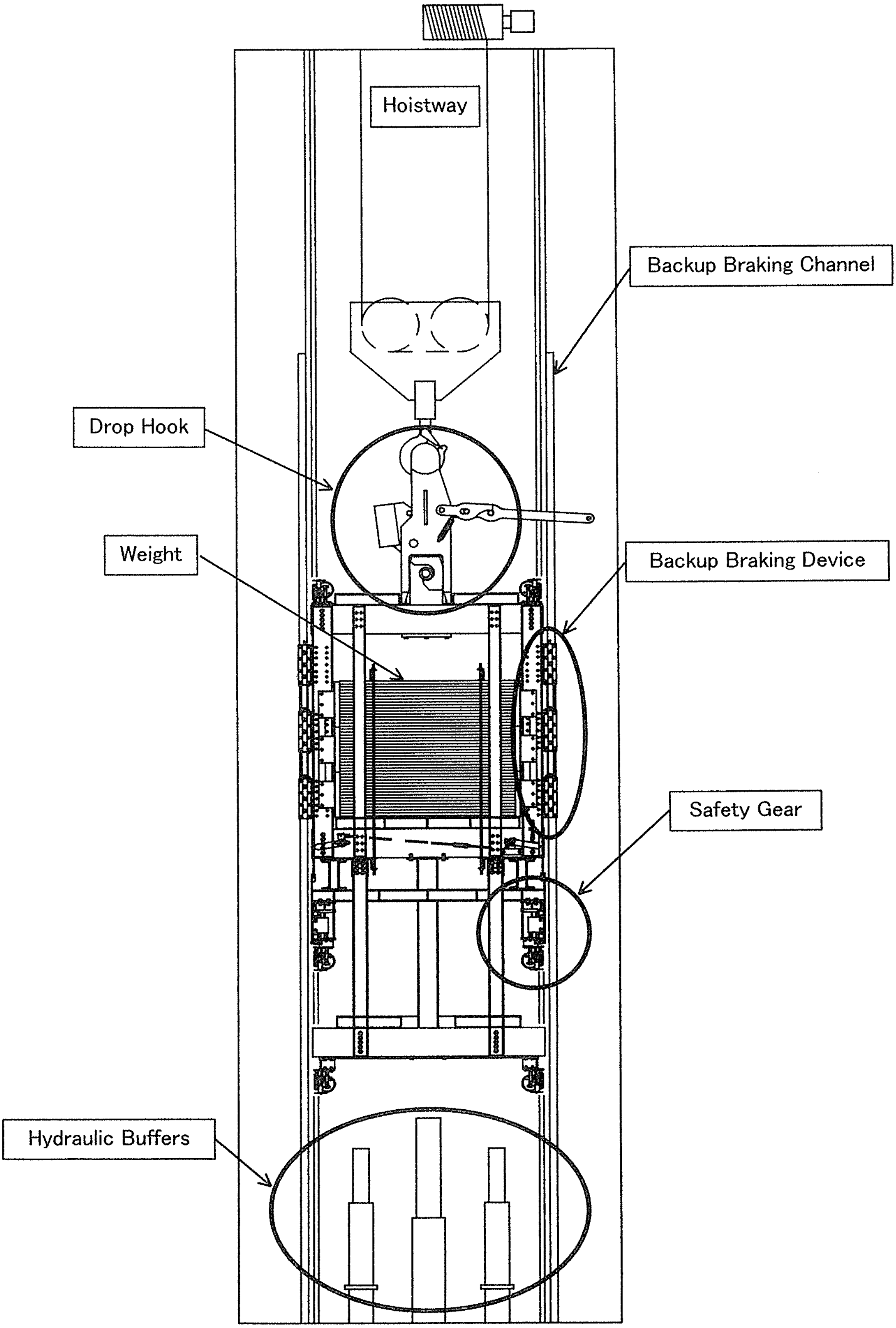

Fig. 7 Drop Test Apparatus for Rated Speed of 1,000m/min

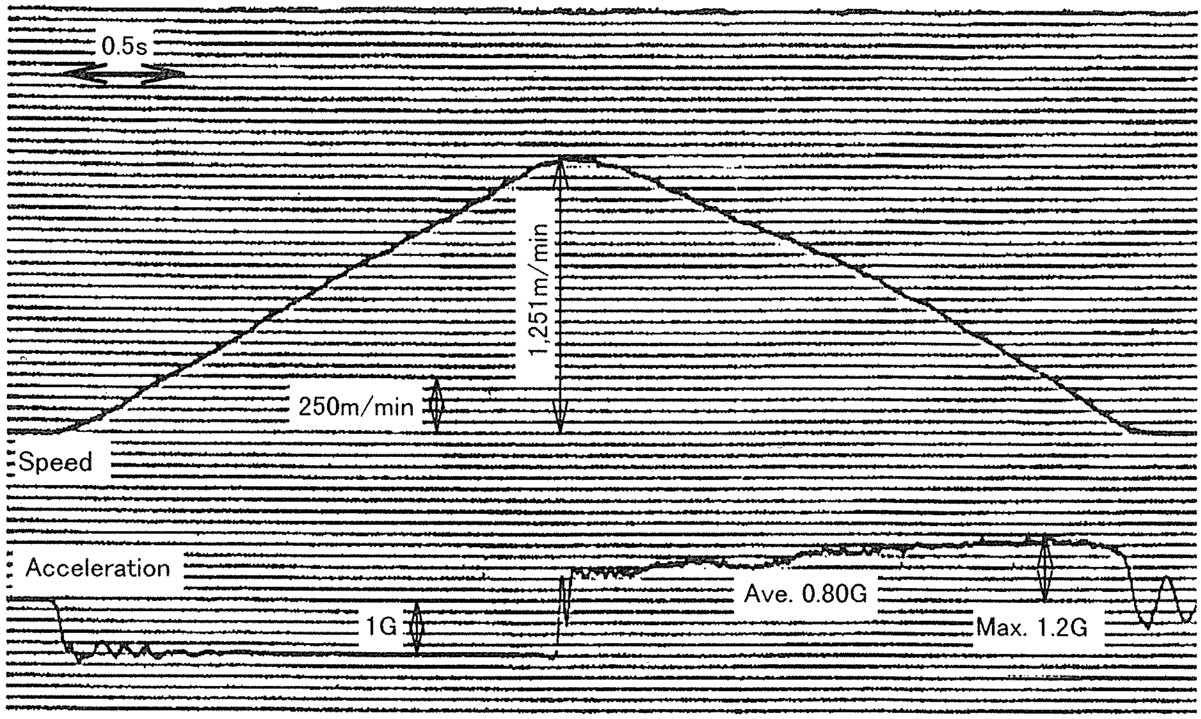

Fig. 8 Results of Drop Test Apparatus at Rated Speed of 1,000m/min

7. Conclusions

1) The development of a safety gear for a rated speed of 1,000m/min and maximum operational mass of 22,700kg has been completed.
2) A friction coefficient about 50% higher compared with those of conventional metallic friction materials was achieved using the friction material of the new safety gear made of a ceramic material whose main ingredient is silicon nitride.

8. References

1) Watanabe, et al., "Development of World's Fastest Elevator and Future View," Japan Society of Mechanical Engineers, Tech Proc., 3rd Transportation and Distribution Sector Seminar, 1-5, 1994.
2) Okada et at., "Development of 810m/min-Class Elevator Safety Gear," Japan Society of Mechanical Engineers, Tech Proc., 4th Transportation and Distribution Sector Seminar, 253-254, 1995.

9. Biography

H. Kobayashi joined Toshiba Corp. in 1990 and is currently assigned to the Elevator and Escalator Development and Design Department, Fuchu Works, Toshiba Corp.
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