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A Study on the control system for the Unintended Car Movement Protection Means to meet the International Standards of lifts

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Abstract – As the number of tall buildings is increasing, the high-speed lift is necessary in the modern world. Therefore, the further considerations for associated safety devices of lifts were required by the International Standards. In order to stop the moving of cage and keep it, the lifts have to be provided with means that can detect the unintended car movement. Therefore, the International Standard Safety Rules for the construction and installation of lifts had been revised. This paper describes the operation principles of the Rope Brake to fit the Unintended Car Movement Protection (UCMP) means required by the International Standards. This paper confirmed that the performance of these devices was suitable in the scope of the safety standards. This paper also analyzed that the shocks on working of these devices in a car would be dangerous to each passenger differently. Thus, this paper proposes a new design that the circuit diagram of the Unintended Car Movement Protection systems should be improved from the existing design to solve these internal shock problems. So, it is expected to protect passengers from the internal shocks by working of Rope Brake due to irrelevant factors.

Keywords: Lift, Internal shock, UCMP, Control system, Safety standard, Rope brake

1. Introduction

High-speed lifts are being installed in the tall buildings. Therefore, the further considerations of associated safety devices should be studied.

In Korea, for the last ten years (2006-2015), 289,588 new lifts were installed by 6.55 % annual average growth rate every year. During this period, according to the accident investigation on lift, 1,035 lift accidents had occurred. The average accident rate per installation was 0.0256 %. On the analysis of the accident situations during the same period, 841 cases (81.25%) of the total accidents turned out to be related with user errors. A failure in manufacturing and maintenance was accounted to 170 cases (16.42%), which was the second highest source of lift accidents.

According to the analysis results of damage degree by lift accidents during the same period, human victims had been closed on 1,290 counts. Of these counts, 108 passengers (8.37%) died in lift accident, and 850 passengers (65.89%) were seriously injured [1].

Therefore, the lifts should get the appropriate safety systems to protect the passengers and equipment from these risk factors. So, the International Standard Safety Rules for the construction and installation of lifts had been revised.

Until the 1990s, each country established its own safety rules for lifts. However, after the 2000s, the safety rules for the lifts were divided into those of the North American Standards and European Standards. With the exception of the North American Standards accepted by the United States and Canada, approximately 80% countries of the world have been accepting the European Standards [2-4].

Korea accepted the European Standards in 2005, and applied some parts of them as lift rules to MRL (Machine-Room-Less) lifts. On the basis of the European Standard safety rules for the construction and installation of lifts, the Korean Standards for the electric lifts were completely revised by the government policy concerned. These new revised safety rules had been applied to all lifts in Korea since September 15, 2013. In order to reduce the incidence of death or injury by the lift accidents, these rules required that lifts should be provided with means to stop the Unintended Car Movement away from the landing with the landing door was not in the locked position and the car door was not in the closed position, as a result of failure in any single component of the lift machine or drive control system upon which the safe movement of the car depends, except for the failure of the suspension ropes or chains and the traction sheave or drum or sprockets of the machine. These rules also required that traction drive lifts should be provided with the any means to prevent the ascending car over-speed.

In addition, the car must be stopped at a distance that is not exceeding 1.2(m) from the landing when the Unintended Car Movement is detected, and it must not allow deceleration of the empty car in excess of 1 g_n

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(acceleration of gravity acceleration of gravity) during decelerating [5].

Nowadays, in addition to safety gear of traction machine, manufacturers are designing an additional device such as a Car Brake, Rope Brake, or Dual Brake for these requirements to prevent the Unintended Car Movement. One of these, a Rope Brake device can be the most obvious safety system because it works directly on the ropes of lift. Therefore, a Rope Brake system has been commonly used.

Besides, if a Rope Brake device works on the ropes that are running at a rated speed, the internal shock degree is actually influenced by the loading, rated speed and deceleration.

Until now, the many studies have examined the performances of Rope Brake system for the safety rules. Nevertheless, there are very few experimental studies on the internal shock degree by the Rope Brake system working.

This paper describes the operation principle of the Uncontrolled or Unintended Car Movement Protection (UCMP) means on this type, and it also analyzes the experimental results of the internal shock degree with various situations.

2. Principle of Traction Drive Lifts and Emergency Stop Devices

A structural system of traction drive lift consists of a drive motor, car, counterweight, main sheave, ropes and traction machine including brake device. Fig. 1 shows a structure of traction drive lift.

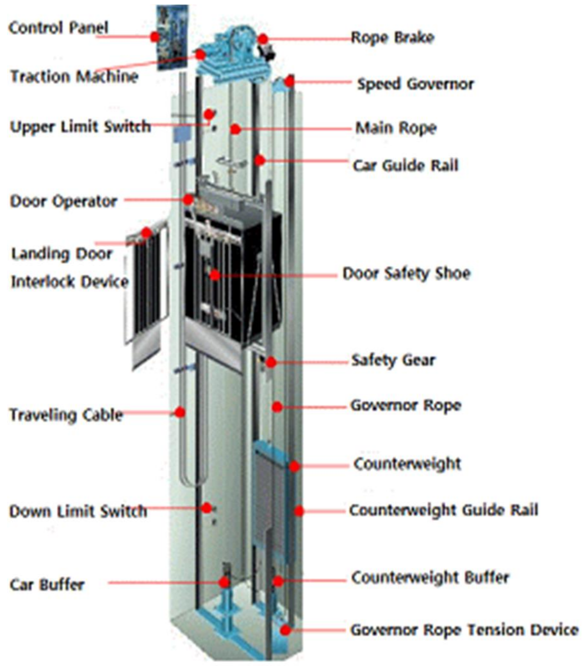
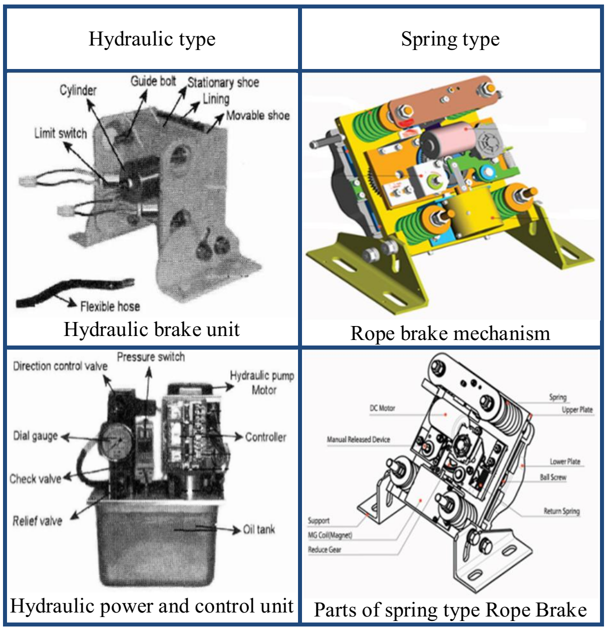


Fig. 1. Structure of traction drive lift



Hydraulic brake unit

Rope brake mechanism

Hydraulic power and control unit

Parts of spring type Rope Brake

Fig. 2. System configurations of Rope Brake

On the upper structure of traction drive lift, the car is hanging at one end of the main ropes and the counterweight is hanging at the other end of the main ropes.

Normally, brake devices of traction machine cannot stop the moving of lift mechanically if it slips down slowly caused by unbalancing of weight when the friction between sheave and ropes is decreased or the brake system is out of order at the landing door position. In addition, too, brake devices cannot stop the moving of lift mechanically on uncontrolled over-speed running to up direction. Definitely, it must be serious problems.

To solve these serious problems, the Unintended Car Movement Protection means that have detection function to prevent the ascending over-speed have been developed as additional safety device to the emergency safety gear.

One of these additional devices, the Rope Brake is classified to two types of a hydraulic type Rope Brake and a spring type Rope Brake, as shown in Fig. 2.

The working principle of hydraulic type Rope Brake system can be explained in these words that the safety circuit interruption by detecting an error signal is caused to open the limit switch contactors so that the solenoid power supply works.

If the cylinder pressure is equal to the setting pressure of the hydraulic supply unit with switching of the direction control valves, the main ropes will be gripped immediately by working of the solenoid shoes [6].

The working principle of the spring type Rope Brake system can be explained in these words that the front and back covers are connected with the two axes, and the connected spring force from the slider makes the braking force to grip the main ropes. This type has an advantage that it can make large braking force with small force from the bottom of the slide forming wedge to grip the ropes.

In addition, the manufacturing process of the spring type Rope Brake device is simpler and more economical than the conventional hydraulic Rope Brake device [7].

Fig. 3 shows an installation drawing of a Rope Brake device and traction drive lift to analyze the dynamic force.

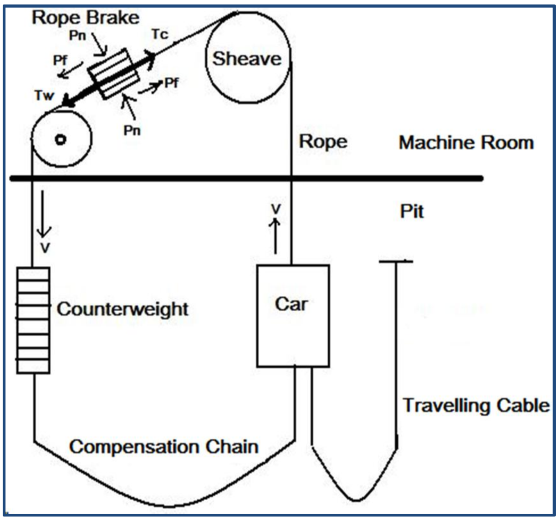


Fig. 3. Installation drawing of Rope Brake device and traction drive lift

where,

Tw : Tension in the direction of counterweight,
Tc : Tension in the direction of car,
P_n : Vertical braking force by gripping ropes,
Pf : Friction on the ropes by P_n to decelerate the car speed.

If a full slipping of car occurs by assuming that friction between the ropes and sheave is completely ignored, the law of inertia applied to structural analysis is expressed as follows [8-9];

$$a = \frac{v}{t} = \tan \propto \tag{1}$$

$$\mathrm{L} = \frac{1}{2} v\mathrm{t} = \frac{1}{2a} v^2 \tag{2}$$

$$\mathrm{P_f} = \Big[(\text{counterweight weight} + \text{car weight} + \text{ropes weight} + \text{compensation chain weight} + \text{travelling cable weight}) \times \Big(\frac{v^2}{2g\mathrm{L}}\Big) \Big] + (\mathrm{OB} \times \text{lated load}) \tag{3}$$

$$\mathrm{P_n} = \mathrm{P_f} / (\cos\theta - \mu\sin\theta) \tag{4}$$

where,

a : Acceleration [m/s^2],
v : Speed [m/s],
∝ : Average speed gradient,
L : Maximum braking distance [m],
g : Acceleration of gravity,
OB : Ratio of the over balance,
μ : Coefficient of friction,
Θ : Included angle between the $\mathrm{P_n}$ and the $\mathrm{P_f}$.

Eq. (4) expresses the braking force working on the slide to grip the ropes. The equation should be calculated as the pressure to stop the car within the maximum braking distance.

In addition, the lift mathematics model is given as follows;

$$\dot{x} = Ax + Bu + Pw + Qd_1 \tag{5}$$

$$\mathrm{y} = \mathrm{Cx} \tag{6}$$

Where the rector x(t) represents the system state, the vector u is the control input (torque), d_1 is the disturbance input to the plant (it may represent a load force acting on the lift car). y is the system output (position of the car). w represents the desired trajectory (position, speed, acceleration and so on).

The equation of motion for a lift model can be expressed as

$$\mathrm{M}\ddot{q} + C\dot{q} + Kq = f_1 u + f_2 w, \tag{7}$$

Where matrices M, C and K respectively represent the mass matrix, the damping matrix and the stiffness matrix, q is a displacement vector, $f_1 u$ is the control input from the motor, and $f_2 w$ is the disturbance input from the eccentric pulleys.

Eq. (7) gives the following state-space equation:

$$\dot{x_e} = A_e x_e + B_{ew} w + B_{eu} u, \tag{8}$$

where,

$$A_e = \begin{bmatrix} I & 0 \\ 0 & M \end{bmatrix}^{-1} \begin{bmatrix} 0 & I \\ -K & -C \end{bmatrix},$$

$$B_{ew} = \begin{bmatrix} I & 0 \\ 0 & M \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ f_2 \end{bmatrix},$$

$$B_{eu} = \begin{bmatrix} I & 0 \\ 0 & M \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ f_1 \end{bmatrix}, \; x_e = \begin{bmatrix} q \\ \dot{q} \end{bmatrix}.$$

If the position of the car is fixed, Eq. (8) becomes a linear state-space equation, which can be dealt with using linear control theory. Therefore, the equation for the output is as follows;

$$y_e = C_e x + D_{ew} w + D_{eu} u \tag{9}$$

Where, D is the non-autonomous input to the external system [10-11].

3. Operation Process of Safety Device

Fig. 4 shows a flowchart of the emergency stop process according to the lift safety circuit diagram.

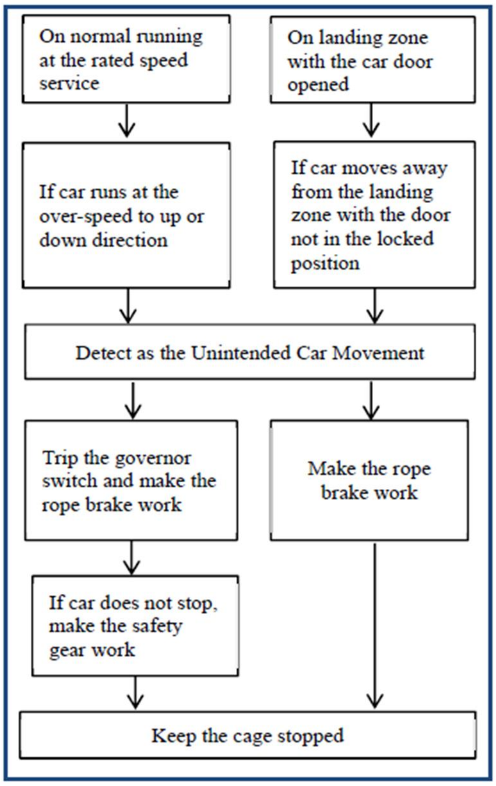


Fig. 4. Flowchart of emergency stop process

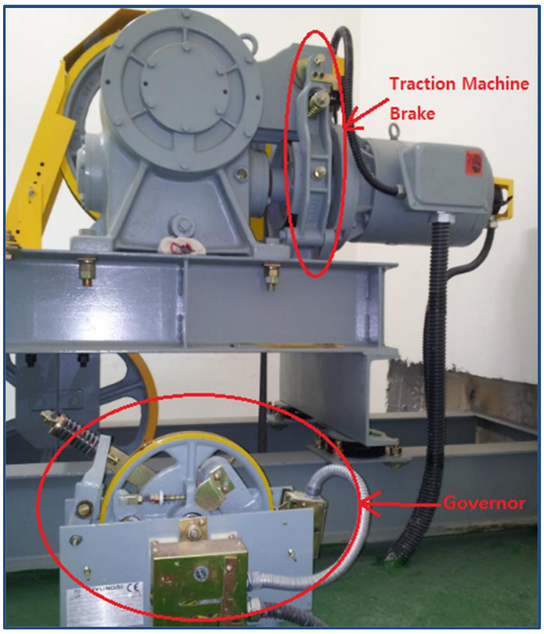


Fig. 5. Traction machine brake and governor

3.1. Emergency stop system of traction machine

Of course, a traction drive lift must have the safety gear that can make the cage stop and hold it in down direction by tripping the governor switch and gripping the rails even if the brake device is broken. The safety gear device should be located at the lower part of the cage as possible.

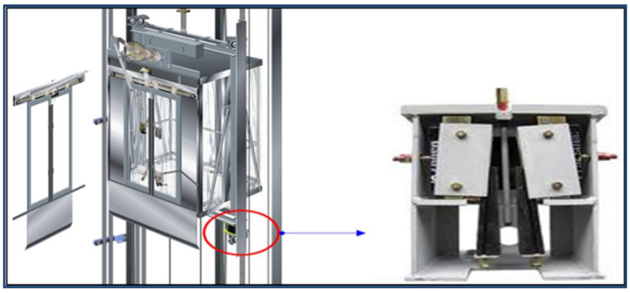


Fig. 6. Safety gear

The tripping of the over-speed governor switch to make the safety gear work should be happened at a speed at least equal to 115 % of the rated speed and less than the regulated safety speed.

For the safety of passengers, electric safety switch that is on the over-speed governor must be tripped to stop the drive motor before or at the moment when the cage safety gear works.

Thus, at first, the over-speed governor switch and the traction machine brake should be able to stop the drive motor at the uncontrolled speed. At second, the safety gear should be able to keep the cage stopped. Fig. 5 shows the traction machine brake and governor. Fig. 6 shows the safety gear and its location.

3.2 Uncontrolled or Unintended Car Movement Protection (UCMP) system

This chapter explains the Unintended Car Movement Protection system required by the European Standards.

As protection from the uncontrolled car overs-peed, tripping the switch of the over-speed governor must make the car safety gear work at a less than the regulated safety speed. In addition, this working must stop the drive motor with means of electric safety device.

If the safety system detects an uncontrolled speed exceeding the rated speed, the safety gear of cage or counterweight must be operated by its own over-speed governor.

On the other hand, the Rope Brake must be operated as means to stop the unintended car movement away from the landing with the landing door not in the locked position and the car door not in the closed position, as a result of a failure in any single component of the lift machine or drive control system upon which the safe movement of the car depends, except failure of the suspension ropes or chains and the traction sheave or drum or sprockets of the machine. Here, the means should be able to detect unintended movement of the car so that the means should be able to stop the car and keep it stopped. In addition, this Rope Brake must be operated in tripping the switch of over-speed governor linked.

Fig. 7 and 8 show the wiring diagram with the Rope

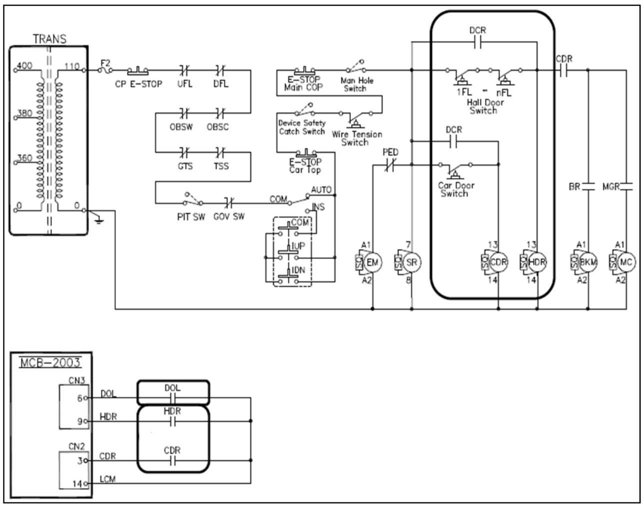


Fig. 7. Wiring diagram with detection system of the door closed or not

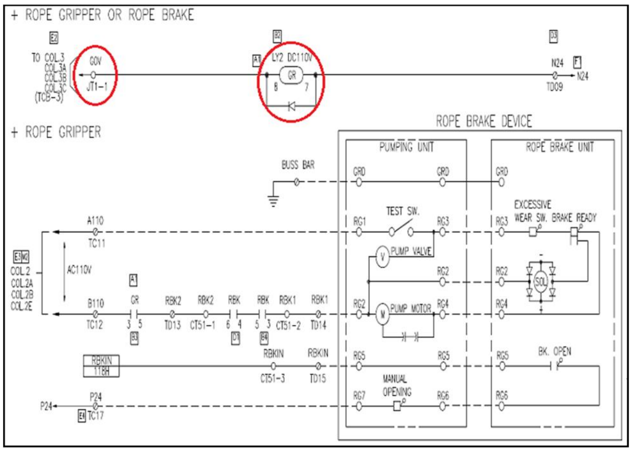


Fig. 8. Wiring diagram with operation of Rope Brake

Brake connected to the electric contacts of the door interlock system and governor switch.

As above the diagram, most of the rope brakes are linked with the over-speed governor switch without regard to passengers about internal shock. So, these rope brakes will be able to be operated by tripping of governor switch at a just vertical vibration when passengers may simply jump in a car just for fun. In these cases, the in-car shock degree will be able to be fatal to elders, kids or weak passengers. It must be serious problem of the Rope Brake system in spite of the safety rules.

4. Analysis of the Experimental Results

The following experiment in this paper is one of many field experiments while inspecting lifts and the measured values are little different in repeated or replicated measurements of model.

Table 1 explains three situations for the experiments. As each case in table 1, through these experiments, this paper measured the braking distance, deceleration and in-car shock degree when the Rope Brake was working.

Table 1. Three situations for the experiments

	Situations
Case 1	When only the traction machine brake was working by tripping the switch of governor at the rated speed 1.5(m/s) running.
Case 2	When the Traction Machine brake and the Rope Brake were working at the same time by tripping the switch of governor at the rated speed 1.5(m/s) running.
Case 3	When only the Rope Brake was working by detecting the unintended car movement away from the landing zone with its door left open.

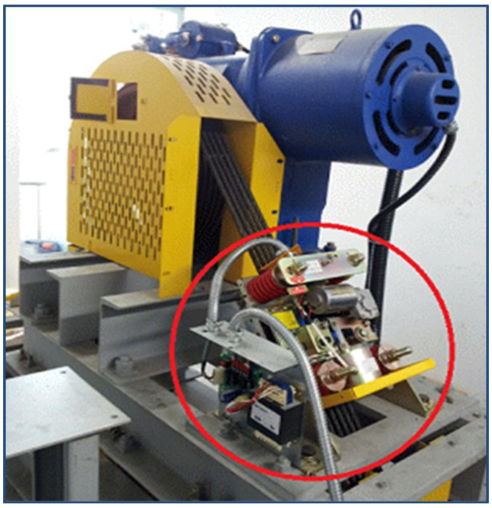


Fig. 9. Traction machine with the spring type Rope Brake

Here, the EVA-625 was used as the measurement equipment for these experiments.

The EVA-625 is a combined hardware and software approach to record and analyze lift and escalator vibration, speed and noise. The axes of sensitivity for the accelerometer package are called the X, Y, and Z axes. When mounted in the case, the X-axis is from the front to back, the Y-axis is from side to side, and the Z-axis is vertical. The measured recording data can be analyzed on a computer using EVA software.

Fig. 9 shows the traction machine with the spring type Rope Brake used in these experiments. This paper is based on the measured and recorded experimental results of the three situations with the tri-axial accelerometer placed on the floor of the lift.

4.1. Conditions for the experiments

Table 2 shows the conditions of the selected lift for these experiments, and table 3 shows the specifications of the Rope Brake system.

In a speed pattern of lift, there are three travel layers of the acceleration speed from standstill to rated speed,

Table 2. Conditions of the lift

Conditions	Value
Loading weight	1000 kg
Car weight	1020 kg
Transfer distance	46.9 m
Speed	1.5 m/s
Rope	12 Φ x 5
Compensation chain	1 EA

Table 3. Specifications of the Rope Brake system

Property	Value
Electrical rating	Input 24 V DC, 4 A
Rated load	450~1150 kg f
Rope roping	1:1
Rated Speed	Max. 2.5 m/s
Max. tripping speed	Max. 3.02 m/s

constant rated speed and deceleration speed to standstill.

In vibration sections, there is little vibration in the travel section of constant rated speed, but the vibration gets stronger in acceleration and deceleration travel section to up or down direction.

The vibration width of the X-axis and Y-axis is limited structurally by guide rails, because the motion of lift hanged by ropes is vertical.

Therefore, the vertical vibration of the Z-axis direction is an important factor to ensure the quality of the ride. Accordingly, the vibrations of the X-axis and Y-axis direction do not need to be considered relatively.

So, this study analyzed the vertical channel for lift vibrations, deceleration pattern, and jerk using these sections. In addition, it analyzed the in-car shock degree through the spectrum-Z channel.

4.2 Shock of the traction machine brake working by the governor switch tripping

Fig. 10 shows the speed pattern and vibration when only the traction machine brake was operated by governor switch tripping at the rated speed 1.5(m/s) running with assuming the over-speed .

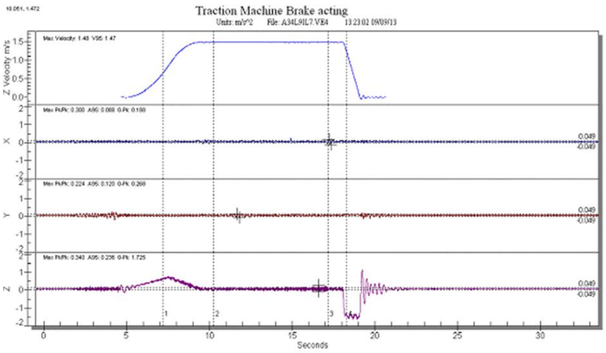


Fig. 10. Speed pattern and vibration by the traction machine brake working

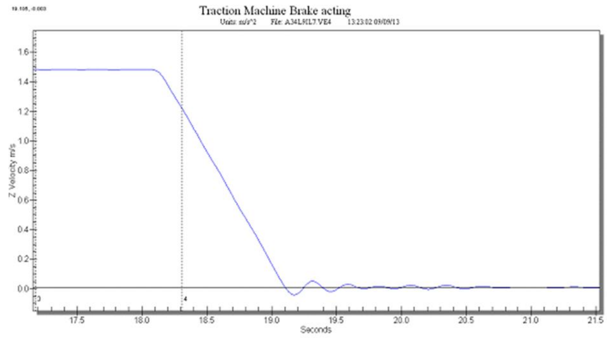


Fig. 11. Deceleration pattern by the traction machine brake working

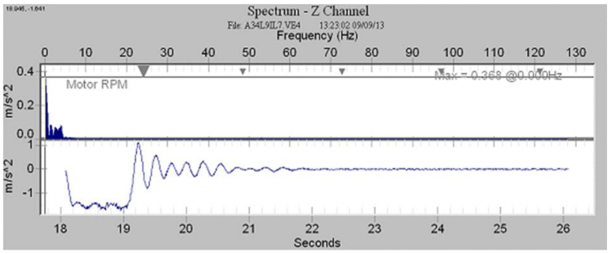


Fig. 12. Shock degree by the traction machine brake working

Fig. 11 shows the deceleration pattern by only the traction machine brake working. Here, the braking time is 1.054(s), the braking distance is 0.791(m), and the average deceleration is 1.423(m/s^2).

The vertical maximum deceleration is 1.641(m/s^2) in the section of abrupt deceleration, as shown in Fig. 12.

4.3 Shock of the traction machine brake and rope brake working at the same time

Fig. 13 shows the speed pattern and vibration when the Traction Machine Brake and the Rope Brake were operated at the same time by governor switch tripping at the rated speed 1.5(m/s) running with assuming the just vertical vibration.

Fig. 14 shows the deceleration pattern by the Traction Machine Brake and the Rope Brake working at the same time. Here, the braking time is 0.766(s), the braking distance is 0.575(m), and the average deceleration is 1.958(m/s^2).

The vertical maximum deceleration is 9.194(m/s^2) in the section of abrupt deceleration, as shown in figure 15.

4.4. Shock of the Rope Brake working by detecting the unintended car movement

Fig. 16 shows the speed pattern and vibration when only the Rope Brake was operated by detecting the unintended car movement as if the car was slipping to up direction with its door opened and the traction machine brake was broken.

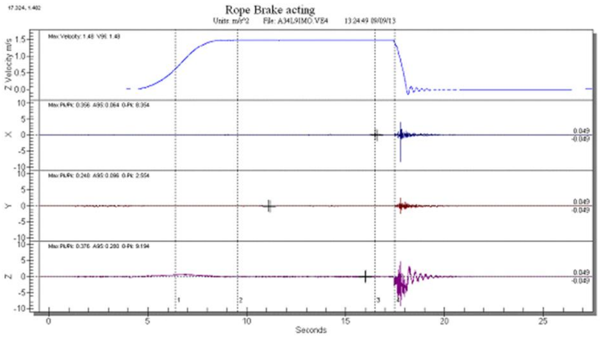


Fig. 13. Speed pattern and vibration by the Traction Machine Brake and the Rope Brake working

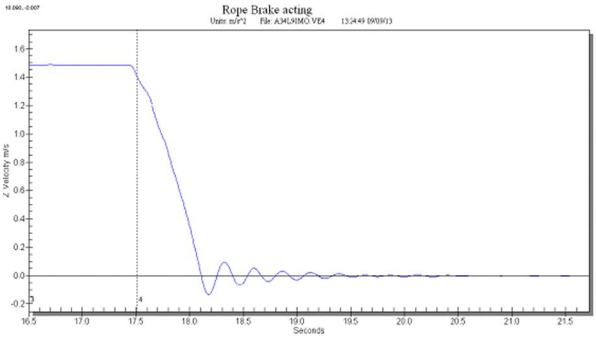


Fig. 14. Deceleration pattern by the Traction Machine Brake and the Rope Brake working at the same time

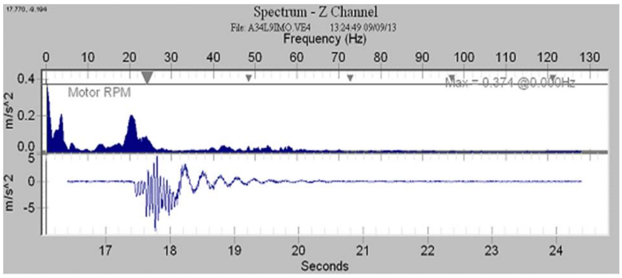


Fig. 15. Shock degree by the Traction Machine Brake and the Rope Brake working at the same time

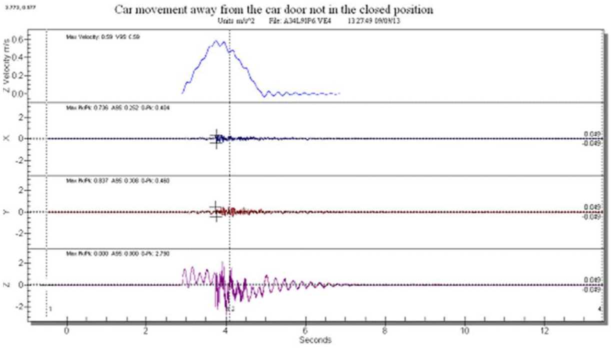


Fig. 16. Speed pattern and vibration by the Rope Brake working

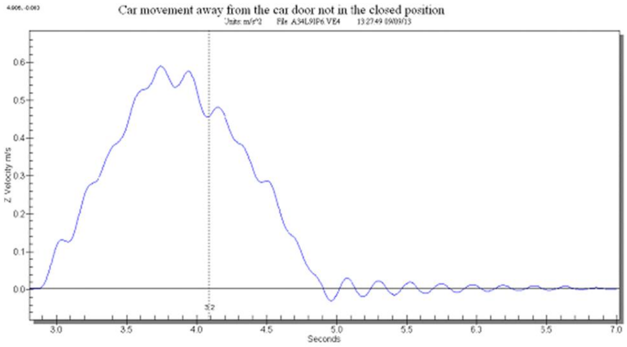


Fig. 17. Acceleration and deceleration pattern by the Rope Brake working

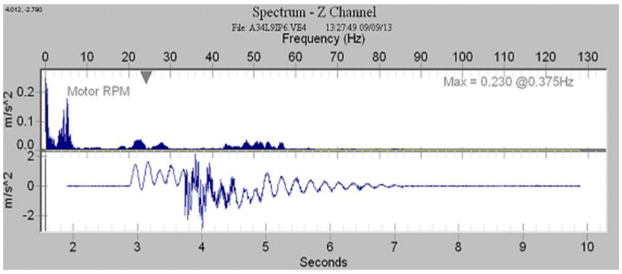


Fig. 18. Shock degree by the Rope Brake working

Table 4. Summary of the experimental results

	Case 1	Case 2	Case 3
Braking time [s]	1.054	0.766	2.004
Braking distance [m]	0.791	0.575	0.577
Average deceleration [m/s^2]	1.423	1.958	0.509
Maximum deceleration [m/s^2]	1.641	9.194	2.790

Fig. 17 shows the acceleration and deceleration pattern by only the rope brake working due to detecting the unintended car movement. When the car moved with its door opened, the Rope Brake began to work at that time. The speed of slipping point is 0.577(m/s), so it was slipped to 0.251(m) for 0.871(s). Here, the total braking time is 1.133(s), the braking distance is 0.326(m), and the average deceleration is 0.509(m/s^2). The uncontrolled moving time is 2.004(s) and the total slipping distance is 0.577(m) from the slipped point with its door opened to the stopped point. The vertical maximum deceleration is 2.790(m/s^2) in the section of abrupt deceleration, as shown in figure 18.

Table 4 is the summary of these experimental results, and figure 19 shows the comparison graph for its results. All cases of these experiments are meeting the European Standard “EN-81+A3 Part 1: Electric lifts” that the braking distance should not exceed 1.2(m) and not allow a retardation excess of 1(g_n).

On this analysis, when the Traction Machine Brake and the Rope Brake were operated at the same time, the vertical maximum deceleration 9.194(m/s^2) of case 2 is 5.6 times larger than common case 1 of the traction machine brake

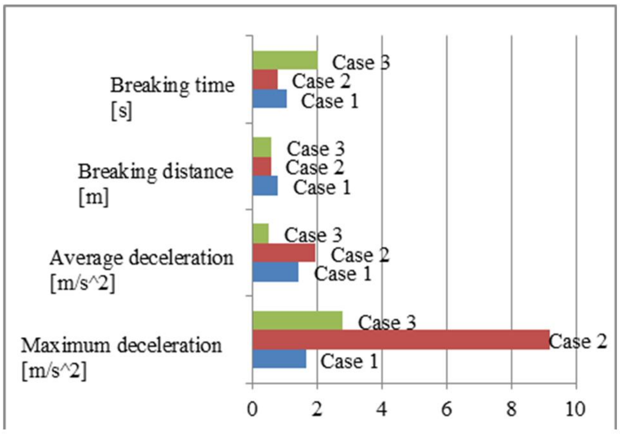


Fig. 19. Comparison graph for the experimental results

working only. The results of case 2 are close to the limitations of the European Standard. Therefore, the uncontrolled in-car shock by the Rope Brake working at the over-speed running will be able to be fatal to passengers in different situations.

5. Conclusion

According to these experimental results, above control system for the Rope Brake working in the wide sense to protect passengers from the uncontrolled or unintended car movement such as the ascending car over-speed is suitable to the requirements of the European Standard for the lifts.

On the other hand, the Rope Brake will grip the ropes when the traction machine brake grips the drum at the same time if the two systems are not independent of each other when the irrelevant factors that are not the uncontrolled car movement such as vibration, mischief or mechanical error are detected. Then, in-car shocks will be able to be fatal to elders, kids or weak passengers. Here, this paper has confirmed these worries through the experiments and wants the existing system to be improved.

In conclusion, this paper proposes an improved design that is an independent safety circuit diagram, for example, the control system of the Rope Brake and Traction Machine Brake should be separated from each other. Even if the Rope Brake is a suitable device to prevent the unintended car movement with its door left open, but the operating process of the Rope Brake should be independent from the detection of governor switching.

In other words, above the integrated control process including the safety circuit diagram with two electric contacts of the unintended car movement and the car over-speed must be separated into independent process. Therefore, the Rope Brake should not react to switching of governor.

A study on the internal shock of lift needs to proceed with the system of speed up in the future.

This paper wants these experimental results to be applied to develop an optimal operating process for the Rope Brake system by designers and engineers. Also, the applications of these experimental conclusions are expected to be useful information in improvement of the Standards of Lifts to ensure the passenger safety.

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