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Make-up of a Simulator having the Same Brake Characteristics as Actual Elevator Emergency Stop Device

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Abstract – The authors study a novel type of elevator emergency stop device which enables to soften impact force at an emergency halt. A new structure of emergency stop devices has been already proposed by our laboratory and also its characteristics has been already proposed by our laboratory and also its characteristics has been shown by digital simulations[1]. In order to confirm the actual effects of our proposed emergency stop device, we have made up a simulator having the same characteristics as the conventional emergency stop device to accomplish the experiments from now on. In this paper, this process is introduced.

Keywords: Elevator, Emergency stop device, Simulator, Brake characteristics, Safety

1. Introduction

In recent years, many skyscrapers are found world-wide and a demand for more rapid elevators becomes higher and higher. The elevators with speed over 1000m/min have already been developed and installed. Together with speedup of elevators, the performance of emergency stop device has also been improved to suit for the speed.

Fig. 1 shows the structure of elevator system. In order to stop the elevator when a serious malfunction occurs on the system, several safety devices are provided such as electro-magnetic brake, emergency stop device, and buffer. One of them is our study target, namely "elevator emergency stop device". The elevator emergency stop device is basically composed of wedge, U-shaped spring and pulling rod as shown in Fig. 2 (b). When the speed of elevator exceeded preset value, governor in the machine room operates and pulls up the rod of emergency stop device. Then, wedges hold the guide rail and create the braking force by the friction. The braking force is adjusted by the strength of U-shaped spring.

The deceleration characteristics of the emergency stop device is ideally targeted to be constant value during activation, but it is known that the value sharply increases just before stopping and changes according to the number of passengers in the cage as shown in Fig. 3 [2]. This characteristic causes sometimes a damage of human body at the time of activation, especially for elderly passengers.

In order to improve the deceleration characteristics and reduce the risk of damage for human body, author proposed the new structure of emergency stop device combined with magnetic rheological fluid (hereafter it is described as MRF) damper. Our proposed emergency stop device enables to soften impact force at the activation of the device by the action of MRF damper. The characteristics of the device are now studied through the theoretical analysis, but it is also needed to confirm by the experiments.

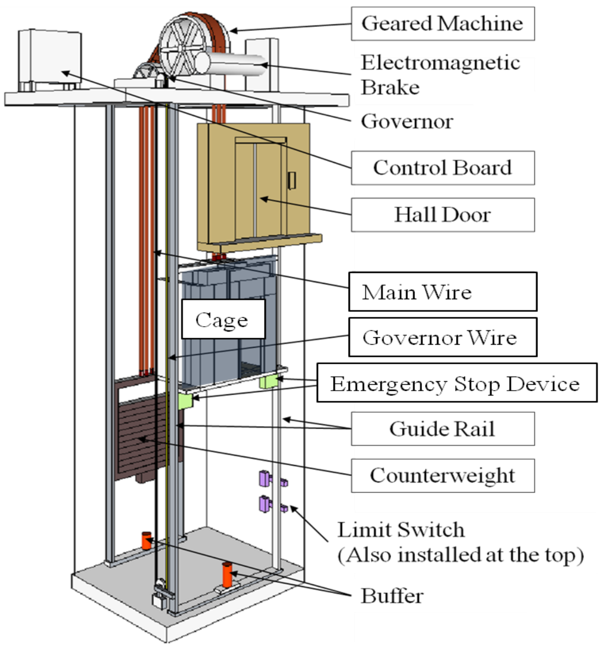

Fig. 1. Structure of elevator system

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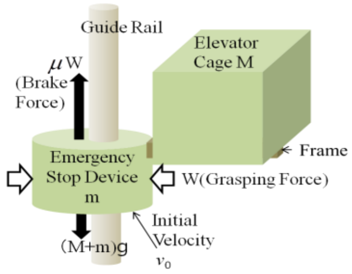
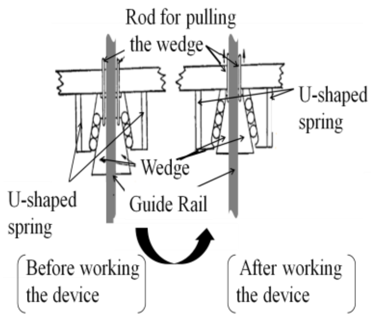


(a) Model of conventional emergency stop device



(b) Detail structure of emergency stop device

Fig. 2. Structure of the device

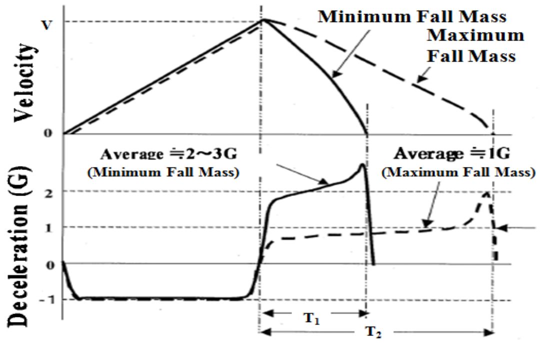


Fig. 3. Deceleration characteristics of conventional emergency stop device

In order to confirm the actual effects of such an emergency stop device by the experiments in the different conditions such as load and speed of elevators, we made up a simulator having the actual brake characteristics of conventional emergency stop device. It will be introduced below.

2. Emergency stop device proposed in our study

Fig. 2 (a) shows a model of a conventional emergency stop device and elevator cage. On the other hand, Fig. 4 shows a model of the proposed device which is composed of the conventional emergency stop device combined with MRF damper and spring in-between with elevator cage.

The MRF is special fluid containing solvent and fine iron powder and it changes its viscosity according to the magnitude of the inputted magnetic field to the fluid (See Fig. 5). If such fluid is poured to a cylinder, and what's more, the magnetic field inputted to the cylinder is regulated properly, then the pair of piston and cylinder can work as a special damper having a variable damping factor ζ [3] (See Fig. 6 and Fig. 7 (a), (b).) .

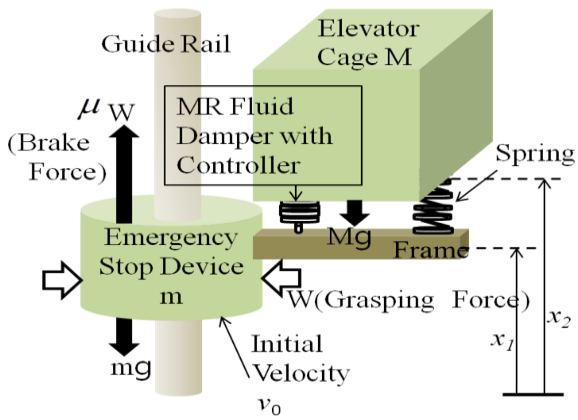


Fig. 4. Model of proposed emergency stop device

Fig. 5. MR fluid

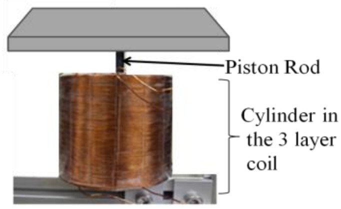
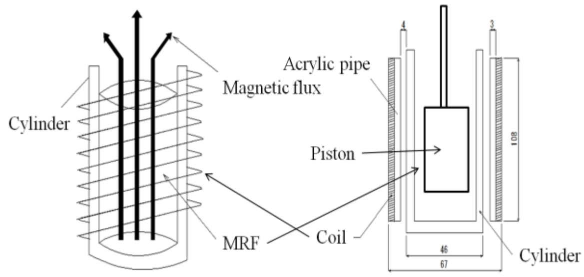


Fig. 6. MRF damper



(a) (b)

Fig. 7. Sketch of MRF damper

In our study, the favorable linear characteristics shown in Fig. 8 have been just obtained, where the magnetic field is regulated by current of the coil wound on the cylinder. In this figure, "1-layer of coil" means the coil wound directly on the cylinder via an acrylic pipe, "2-layers of coil" means the coil wound again on the above-mentioned coil via an acrylic pipe, and also "3-layers of coil" means the coil wound once again on the 2-layers of coil via an acrylic pipe. The number of coil-turn per a layer is same but the resistance of coil per a layer is slightly different because of the difference of diameter of the pipes (See Table 1.).

In order to confirm the relation between the coil current and the magnetic flux density, the magnetic flux density generated by electrifying to the coil has measured at the center point of the lid of the cylinder and is shown in Fig. 9. Also at other points of the lid, the measured magnetic flux density values are almost same within 10% difference.

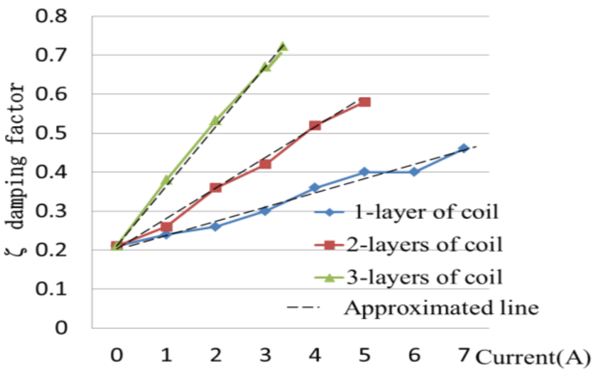


Fig. 8. Relation between coil current and damping factor

Table 1. Dimension of coil

	1-layer	2-layers	3-layers
Resistance	1.3 ohm	2.8 ohm	4.7 ohm
Turns	297 turns	594 turns	891 turns

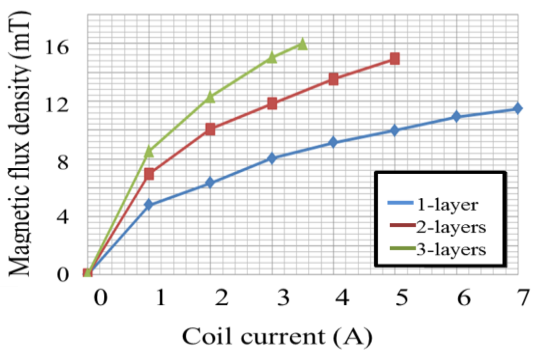


Fig. 9. Relation between current and magnetic flux density

Now, supposing that x_1 and x_2 are defined as shown in Fig. 3 respectively, M, m and K express the mass of cage, the mass of emergency stop device including its elevator frame and the spring constant respectively, the brake force μW is described as F_B and the damper constant C is the sum of C_0 and U, the motion equations of the proposed system shown in Fig. 4 are as follows, where C_0 expresses the value of damper constant in case that the coil current is zero and U expresses the additional value of damper constant by the inputted coil current.

$$m\ddot{x}_1 = K(x_2 - x_1) + (C_0 + U)(\dot{x}_2 - \dot{x}_1) + F_B - mg \quad (1)$$

$$M\ddot{x}_2 = -K(x_2 - x_1) - (C_0 + U)(\dot{x}_2 - \dot{x}_1) - Mg \quad (2)$$

Hence,

$$\ddot{x}_1 = \frac{K}{m}(x_2 - x_1) + \frac{(C_0 + U)}{m}(\dot{x}_2 - \dot{x}_1) + \frac{1}{m}F_B - \alpha_g \quad (3)$$

$$\ddot{x}_2 = -\frac{K}{M}(x_2 - x_1) - \frac{(C_0 + U)}{M}(\dot{x}_2 - \dot{x}_1) - \alpha_g \quad (4)$$

where, the perturbation term α_g means the gravity acceleration. Equations (3) and (4) are rewritten to the following state space notations (5) and (6).

$$\begin{pmatrix}\ddot{x}_1\\ \ddot{x}_2\\ \dot{x}_1\\ \dot{x}_2\end{pmatrix} = \begin{pmatrix} -\frac{C_0+U}{m} & \frac{C_0+U}{m} & -\frac{K}{m} & \frac{K}{m}\\ \frac{C_0+U}{M} & -\frac{C_0+U}{M} & \frac{K}{M} & -\frac{K}{M}\\ 1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{pmatrix}\begin{pmatrix}\dot{x}_1\\ \dot{x}_2\\ x_1\\ x_2\end{pmatrix} + \begin{pmatrix}\frac{1}{m} & -1\\ 0 & -1\\ 0 & 0\\ 0 & 0\end{pmatrix}\begin{pmatrix}F_B\\ \alpha_g\end{pmatrix} \quad (5)$$

$$y = \ddot{x}_2 = \begin{pmatrix}\frac{C_0+U}{M} & -\frac{C_0+U}{M} & \frac{K}{M} & -\frac{K}{M}\end{pmatrix}\begin{pmatrix}\dot{x}_1\\ \dot{x}_2\\ x_1\\ x_2\end{pmatrix} + \begin{pmatrix}0 & -1\end{pmatrix}\begin{pmatrix}F_B\\ \alpha_g\end{pmatrix} \quad (6)$$

As you know, if the perturbation terms F_B and α_g are inputted to the system described in (5) and (6), the output y will be obtained easily by digital simulations. In fact, many fruitful results were obtained in our former paper [1] as shown in Fig. 10, under the condition that the damping coefficient $C=C_0+U$ is fixed by constant coil current. Such an approach for softening the impact to the elevator cage is a kind of passive control because the coil current is constant. In our next paper, a nonlinear semi active control method for this elevator system will be proposed.

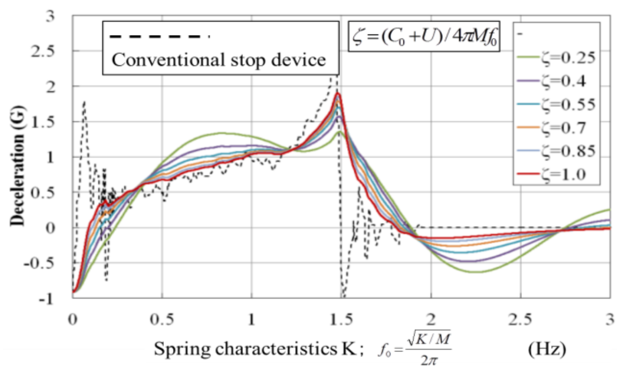


Fig.10. Deceleration softened by the proposed damper [1]

Anyway, the present aim of our study is to soften the impact force in the elevator cage in case of emergency halt. In other words, our aim is to lessen the twice derivative of x_2 in (6). Therefore only one way we have to do is to evaluate through many experiments whether the acceleration of cage with the proposed MRF damper and a spring is lessened or not, compared with that of the conventional emergency stop device. For this reason, a test rig is needed for experiments.

In general, the conventional emergency stop device has the brake characteristics shown in Fig. 11 [4]. This data was obtained from a real free fall test of elevator cage and it is known that any other data concerning emergency stop devices is basically similar to this figure. However such experimental characteristics are generally obtained as analog plots. Therefore, in order to use such characteristics as commands to the simulator or as input signals for digital simulations, it must be processed to digital data first of all. Then, the real analog brake characteristics have been processed by the SPLINE interpolation technique in our laboratory.

Also in this study, the frequency characteristics of deceleration curve in Fig. 11 are obtained by means of the FFT analysis as shown in Fig. 12. As Fig. 11 shows the deceleration of brake characteristics, the actual brake force $F_B=\mu W$ (N) in Fig. 2 will be the value multiplied by the total mass ($M+m$), where the grasping force W depends on the property of the U-shaped spring. Therefore the restless characteristics shown in Fig.11 are considered to be caused by the varying friction coefficient μ. In fact, in case of activation of the device, as the temperature between a wedge and a guide rail rises incredibly, the friction coefficient μ may be also varying vastly.

From Fig. 12, it is known that the frequency band of the brake which must be considered in this study is about 5Hz. This fact is very important and also very useful in carrying out many experiments for verifying the effectiveness of the proposed device. In other words, it means that a simulator for recreating the brake characteristics of emergency stop device must respond to up to 5Hz input signals at worst.

Just for our future reference, Fig. 13 (a) and Fig. 13 (b) are obtained as the characteristics of the velocity and the position of the emergency stop device as shown in Fig.11 respectively.

From Fig. 13 (b), it is confirmed that the emergency stop device kept on sliding a distance of about 12mafter it worked. This fact shows how difficult the quick halt of elevator is.

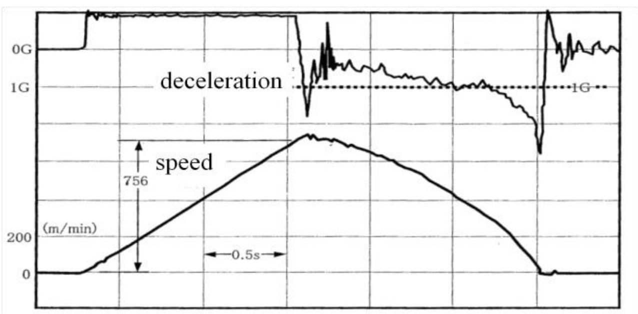


Fig.11. Brake characteristics of emergency stop device

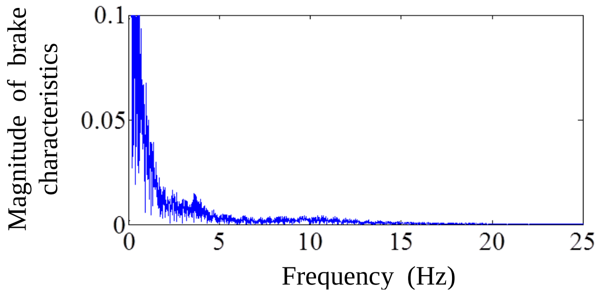
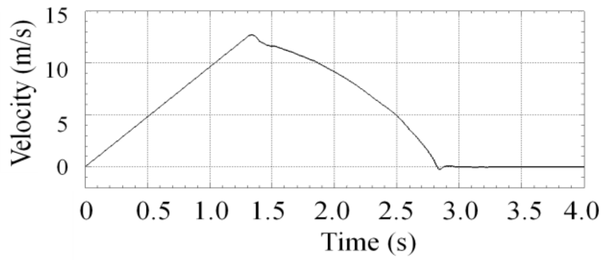
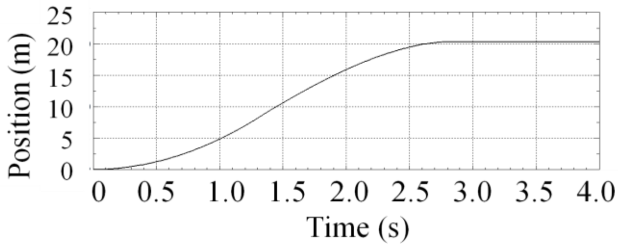


Fig.12. FFT analysis of the brake characteristics (Fig.9)



(a) Velocity characteristics of emergency stop device



(b) Position characteristics of emergency stop device

Fig.13. Characteristics of elevator emergency stop device

3. Make-up of simulator and the whole test rig

In order to carry out many experiments for confirming the characteristics of the proposed emergency stop device, a simulator which generates the actual brake motion is needed. Therefore this time, the simulator which is composed of an induction servo motor, a 3-phases inverter, ball screws, linear guides, support units and couplings has been made as shown in Fig. 14.In addition, Fig. 15 (a), (b) shows power supply circuit and drive circuit of servo-motor respectively for this simulator (See Table II.).

This simulator has about 10cm stroke by transforming the revolution of motor to the heave motion via the ball screw. Input signal is given as a driving voltage to the motor, and the heave motion is applied to the MRF damper and cage components. Those structures of whole rig are shown in Fig. 16.

By giving the input signal which traces the velocity characteristics of actual emergency stop device to this simulator, the characteristics for a speed and acceleration of cage component can be obtained as the output signal from the sensors. Hence, the effect of our proposed emergency stop device can be confirmed by the experiments.

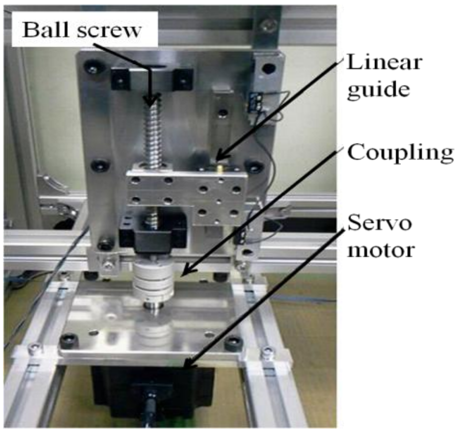
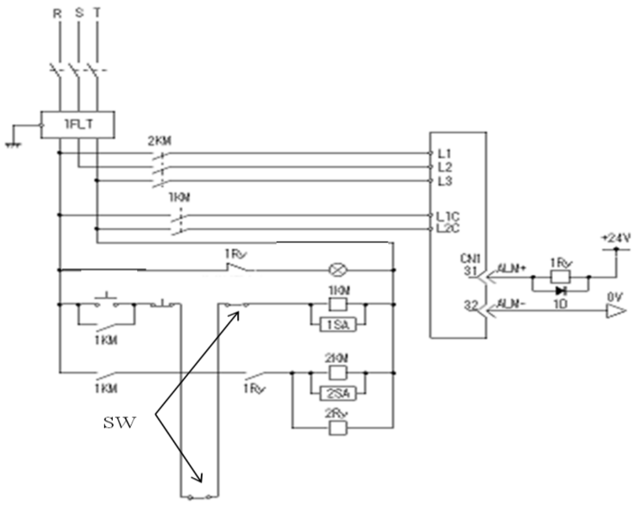
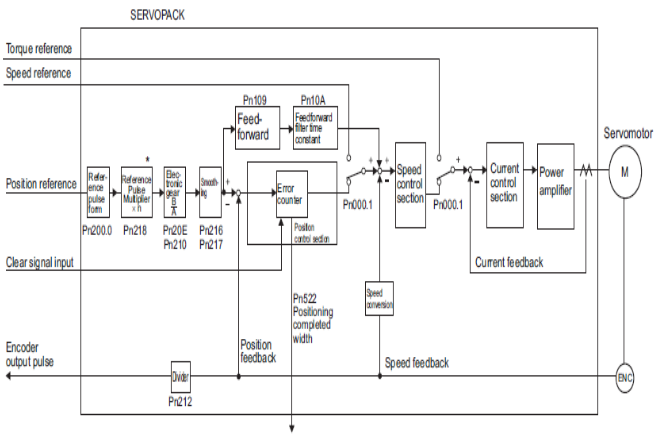


Fig. 14. Simulator for brake characteristics of emergency stop device



(a) Power supply circuit with noise filter



(b) Block diagram of SERVOPACK
(Refer from Yasukawa Control Co.Ltd.)

Fig. 15. Electric Circuit for the simulator

Table 2. Types of simulator components

	Type
Servo Motor	YASUKAWA SGMPS-08A2A2C
Servo Pack	YASUKAWA SGDV-5R5A
Coupling	THK SFC-035DA2-8B-16B
Ball Screw	BNT 1405-2.6

	Type
Support Unit (Fixed Side)	THK BK10
Support Unit (Mover Side)	THK BF10
Linear Guide	THK SSR 15XWY

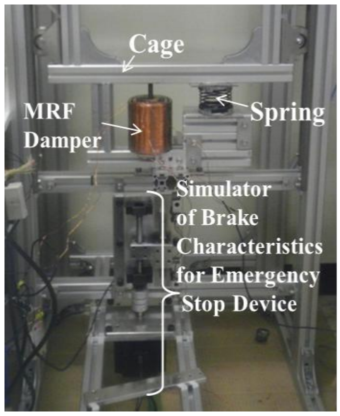


Fig. 16. Test rig with a simulator, spring and MR Fluid damper

4. Evaluations and Conclusions

We have checked the frequency characteristics of this simulator giving 4Hz sinusoidal velocity command. Fig. 17 shows a response of the simulator and Fig. 18 shows frequency characteristics of the simulator. From this figure, it is known that the simulator has sufficient frequency response, because the bandwidth of simulator can reach 10Hz which is wider than 5Hz shown in Fig. 12.

Next, we have carried out an experiment which an input signal was given as a velocity curve of the conventional emergency stop device when activated as shown in Fig. 19, and an output signal was detected as a velocity curve of the cage component as shown in Fig. 20.

From this experiment, the output signal was found to trace well to the input signal, and we confirmed that this simulator has enough ability for recreation of the real brake characteristics of emergency stop device and then quite applicable for the study of our proposed emergency stop device.

5. Future Works

In this paper, in order to verify the effectiveness of the proposed MRF damper, whole test rig and the simulator of emergency stop device have been made. As a result, it is confirmed that the accomplished simulator has enough frequency response to recreate the real brake characteristics.

As a next step, various experiments will be carried out by using this simulator. In addition, a suitable real time controller for such a nonlinear system will be designed in our next paper. In the proposed damper system, effects for softening a shock in an emergency halt will be confirmed with various experiments corresponding to such nonlinear controllers.

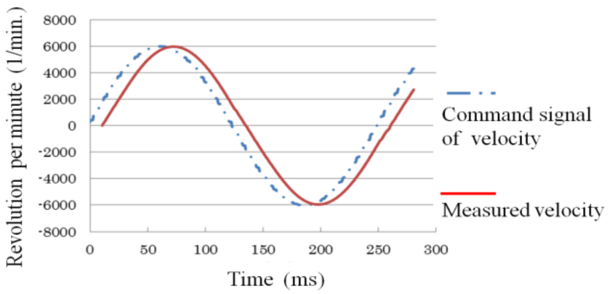


Fig. 17. Velocity responses to velocity commands

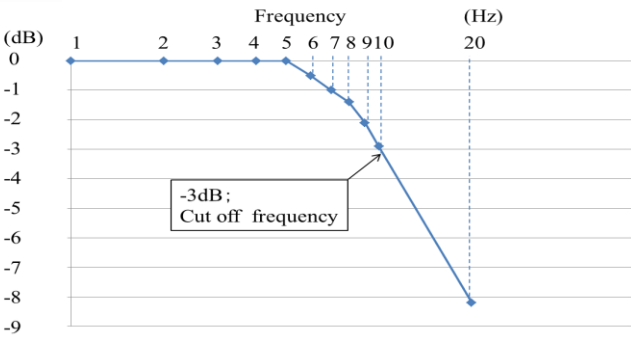


Fig. 18. Frequency characteristics of the simulator

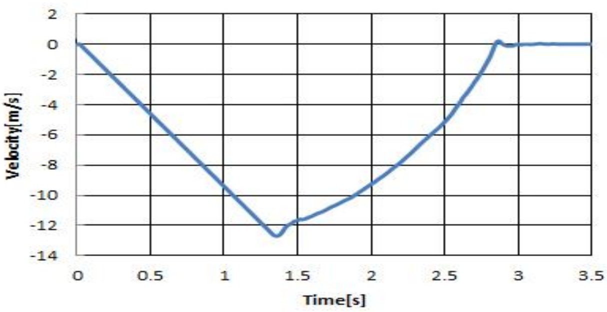


Fig.19. Input signal to the simulator

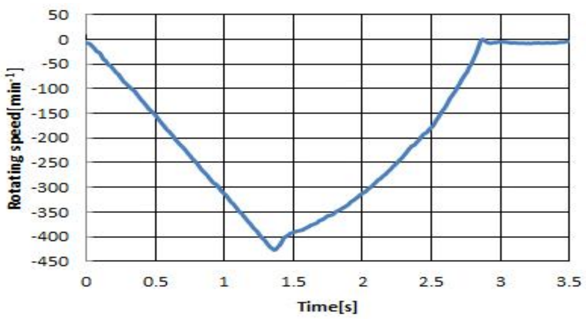


Fig.20. Output signal from the simulator

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