PERFORMANCE TEST AND MATHEMATICAL MODEL SIMULATION OF MR DAMPER

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ABSTRACT :

Semi-active control combining the advantages of mobility in active control system and stability in passive control system, and can be triggered by small amount of energy. Along with the accomplishment on MR damper semi-active research previously, the research aims to develop MR dampers which can be practically applied to real world. The performance dynamic test for both of MR damper and fluid damper are carried on by INSTRON 8800 test machine according with theories of structural dynamics and electromagnetic. Dampers with various sizes are tested and simulated by modified Bouc-Wen modal according to the proper test data. And the parameters of the modal are then identified accordingly. It is believed that the identified processes, in addition to the parameters identified are worthwhile to be referred for the future research need.

KEYWORDS: fluid damper, MR damper, dynamic performance test, modified Bouc-Wen model

1. INTRODUCTION

A compromise between passive and active control systems has been developed in the form of semi-active control systems, which are based on semi-active devices. A semi-active control device has a most charming characteristic that not only can be adjusted timely but also don’t need to force energy into the controlled system. Frequently, such devices are referred to as controllable passive dampers.

Because they offer the adaptability of active control devices without requiring large power sources, semi-active control systems have attracted a great deal of attention in recent years. Many of these systems can operate on battery power alone, proving advantageous during seismic events when the main power source to the structure may fail. Also, because semi-active devices do not inject energy into the structural system, they do not have the potential to destabilize the system either. MR damper is one kind of semi-active devices, and it employs MR fluid to provide its controllable factor.

The MR damper, however, is an intrinsically nonlinear device which makes the design and analysis of suitable control algorithms an interesting and challenging task. The focus of this research is to develop a fundamental understanding of the behavior of MR damper for purpose of designing and implementing this “smart” damping device in structure for natural hazard mitigation.

2. MR FLUID AND MR DAMPER

The background information concern MR fluid and MR damper is introduced in this section. Including the manufacture, the formula and the essential behavior of MR fluid; the manufacture, design and the details of MR damper adopted in this research.

2.1. MR Fluid

MR fluid is composed of micron-size magnetizable particles, some kind of surfactant and carrier fluid. When exposed to a magnetic field, these particles are polarized and attract each other in accordance with the magnetic line as shown in figure 1, resulting in chains of particles within the fluid and raising the viscosity of fluid. The fluid is thus converted from the liquid state to glue type one like peanut butter, at a rapid speed (in milliseconds) and reversibly.

The MR fluid used in this research is made in the Civil Engineering Department of Cheng-Kung University (NCKU), Taiwan. The size of magnetizable particles is seven micrometers in average diameter and the carrier fluid is 1000 cps ($1\text{Pa}\cdot\text{s}=1\text{N}\cdot\text{s/m}^2=1000\text{cps}$) of silicone glue. One proprietary additives of surfactant is adopted to keep magnetizable particles floatable, so the appearance of this MR fluid is even dark gray and sensitive to the magnetic field. The formula of MR fluid used in this research is 30% seven micrometers magnetizable particles, 8% surfactant and 62% silicone glue of 1000 cps.

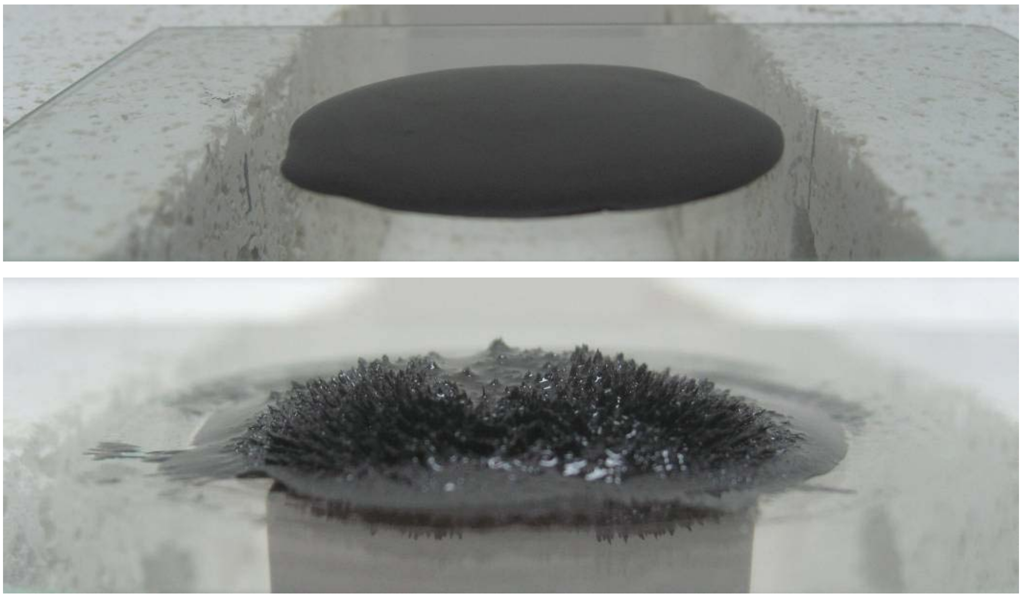

Figure 1 MR fluids on a piece of glass without and with a magnet below it. (Wu, 2007)

2.2. MR Damper

Using MR fluid to provide controllable damping force, MR damper is one kind of semi-active control devices. It is quite promising for civil engineering applications because of its many attractive features such as small power requirement, reliability, and inexpensiveness to manufacture (Ginder *et al.* 1996; Kamath and Wereley 1997; Dyke *et al.* 1998).

The MR damper investigated in this research is a prototype one developed under Department of Civil Engineering of NCKU. The semi-active control device of MR damper is usually retrofitted from passive control device of fluid damper. The dampers in figure 2 are fluid dampers designed and manufactured around seven years ago. A plastic tube entwining enamelled wire as shown in figure 3 is designed so as to generate the magnetic field. This is a particular particle of MR damper developed in this research and the dimensions are shown in figure 4.

For the nominal design, a maximum damping force of 200,000 N (20 tons), the effective fluid orifice is the entire annular space between the piston outside diameter and the inside of the damper cylinder housing.

Movement of the piston causes fluids to flow through this entire annular region. The damper is double-ended, it possesses the advantage of that its' rod-volume compensator does not change the volume of oil chamber by this arrangement. Most of MR damper and other hydraulic damper are assembled with accumulators to reduce the effect of trapped air on damper performance. Nevertheless, accumulator is not designed in the MR damper of this research, because of the enamelled wire is designed to wrap around a plastic sleeve out of the damper. Therefore, the inner conformation of damper is very simple so as to fill with MR fluid. The enamelled wire is designed to be adjustable as it needed. Since enamelled wire is entwined around a changeable plastic sleeve outside the damper, the number of circles and thickness of enamelled wire is changeable. In this research, per centimeter length has 325 circles of enamelled wire. The coils contain a total of about 450 meters of enamelled wire. In order to lead the magnetic line into the chamber of MR damper, a special notch is designed and carved inside the tube of the first damper in the figure 2. The diagram of notch is shown in figure 5 and the difference between chamber with and without notch is discussed below. The completed damper is approximately 100 cm long, has a weight of 80 kg as shown in figure 6. The damper contains approximately 1.8 liters of MR fluid, however, the amount of fluid energized by the magnetic field at any given instant is approximately 94.5 cm^3. The damper has an inside diameter of 15 cm and a stroke of ±3 cm.

Figure 2 Fluid dampers

Figure 3 Plastic tube entwining enamelled wire

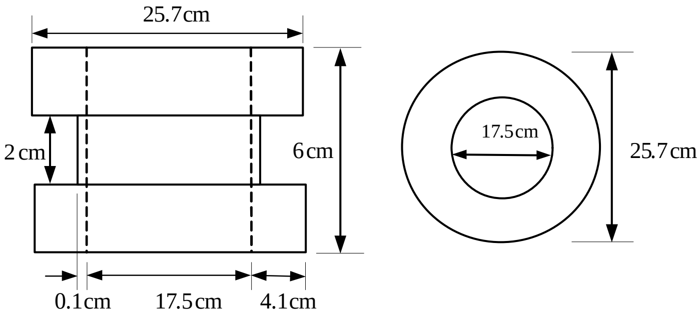

Figure 4 Diagram of the plastic tube

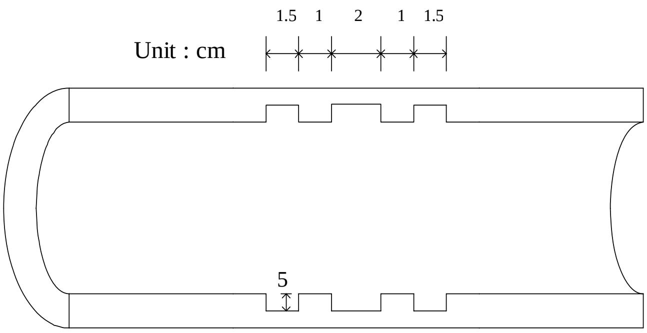

Figure 5 Diagram of the notch

Figure 6 Photo of the MR damper

3. PERFORMANCE TEST

The experimental setup is constructed at the Cheng-Kung University for MR damper testing. The MR damper is attached to an about 4 meters height material test control system as shown in figure 7. Force-displacement and force-velocity tests under sinusoidal displacement excitation are conducted to investigate the fundamental behavior of the MR damper. In this experiment, 1.0, 3.0 and 5.0 mm amplitudes sinusoidal displacement excitations at frequencies of 0.1, 0.3 and 0.5 Hz are employed. The input voltage to the damper coil is constant at 0, 30 and 47 V, respectively.

The effects of changing input voltage are readily observed. As the input voltage increases, the force required to yield the MR fluid in the damper also increases, and a plastic-like behavior is shown in the hysteresis loops. However, the gap between the clamping apparatus and damper causes an approximately 0.5 mm slip at the maximum and minimum positions.

Figure 7 MR damper attached to a material test control system

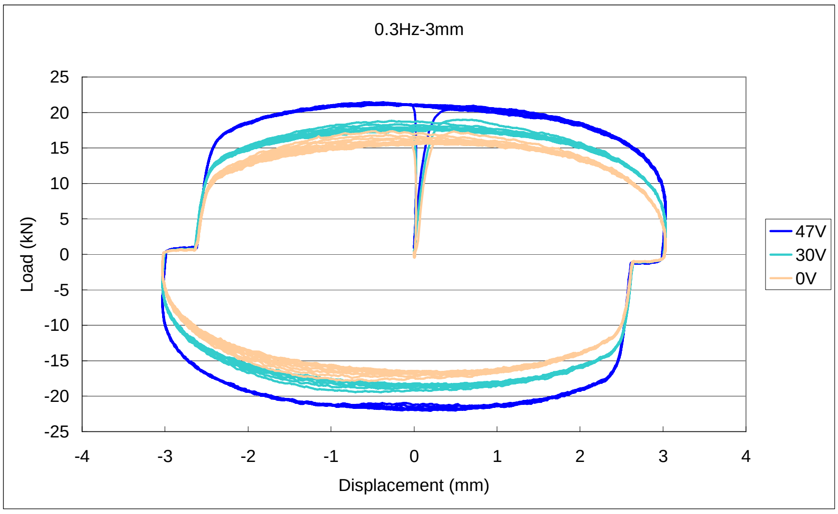

Figure 8 Force-displacement behaviors under a 3.0 mm, 0.3 Hz sinusoidal excitation at various input current

The figure 9 and 10 are the maximum loads of MR damper without notch under the 3mm and 5mm with different frequency excitation. The figure 11 and 12 are the maximum loads of MR damper with the notches inside the chamber under the 3mm and 5mm with different frequency excitation. Based on these figures, the enhancements of the MR damper arise with the increasing voltages are clearer in the case of the MR damper with notches than without notches. That is because the magnetic lines are directed into the chamber of MR damper by the notches, as shown in figure 13, making the MR fluid denser. However, the piston's velocity can affect the capacity of MR damper. Figure 14 shows that enhancements, from 0V to 47V, decrease exponentially as the piston's velocity increases, and Eqn (1) is the increment equation.

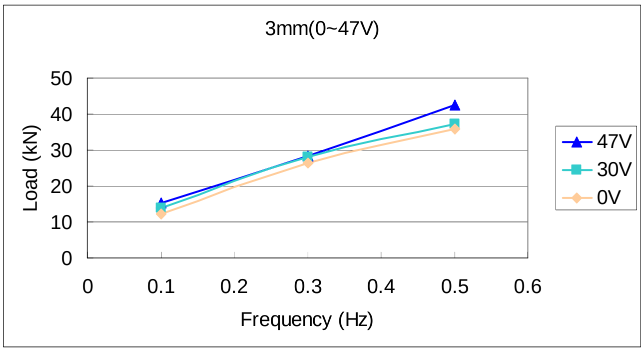

Figure 9 Maximum loads without notch under the 3mm with different frequency excitations

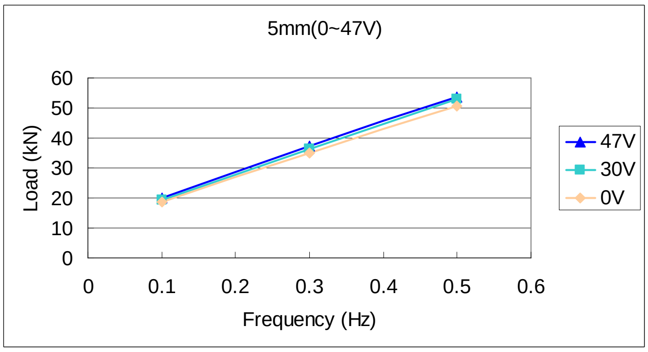

Figure 10 Maximum loads without notch under the 5mm with different frequency excitations

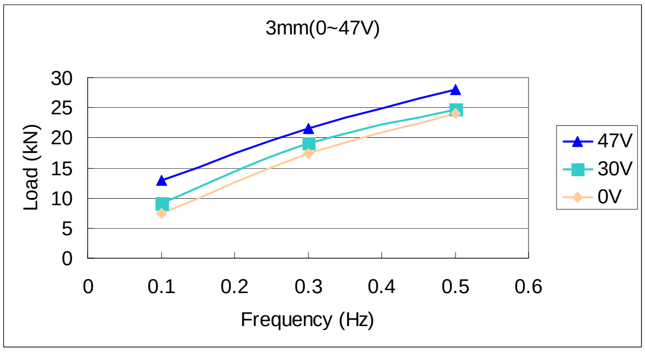

Figure 11 Maximum loads with notch under the 3mm with different frequency excitations

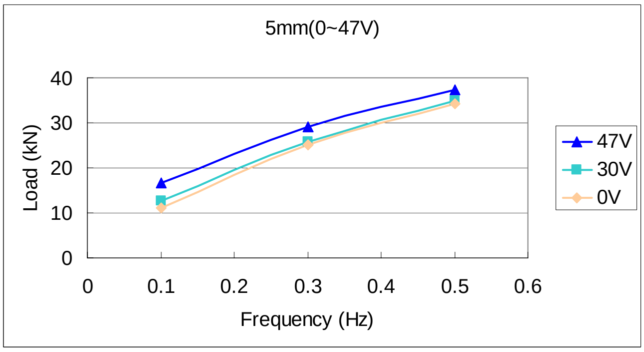

Figure 12 Maximum loads with notch under the 5mm with different frequency excitations

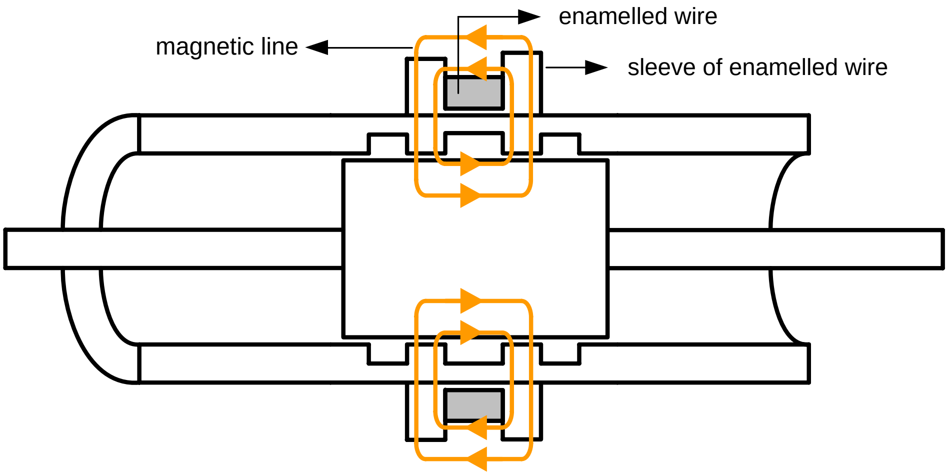

Figure 13 Diagram of the magnetic line led into chamber caused by the notch

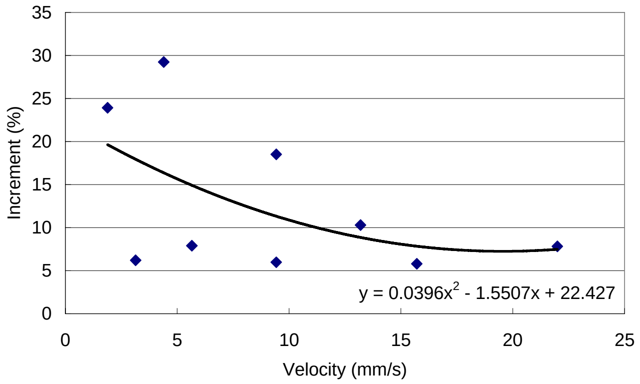

Figure 14 Relationship between load increment and piston velocity

$$\text{Increment} = \frac{\text{Max. Load (47V)} - \text{Max. Load (0V)}}{\text{Max. Load (47V)}} \times 100\% \qquad (1)$$

4. MR DAMPER NUMERICAL MODEL

A memory-dependent, multivalued relation between force and deformation, i.e., hysteresis, is often observed in structural materials and elements, such as reinforced concrete, steel, base isolators, dampers, and soil profiles. Many mathematical models have been developed to efficiently describe such behavior for use in time history and random vibration analyses. One of the most popular is the Bouc–Wen class of hysteresis models, which was originally proposed by Bouc in 1967 and later generalized by Wen in 1976. As the research and development of MR damper, Spencer *et al.* (1997) proposed a phenomenological model for MR dampers based on the Bouc-Wen hysteresis model. The schema of the model is illustrated in figure 15. In this model, the total damper resisting force is given by

$$f = c_1\dot{y} + k_1(x - x_0) \qquad (2)$$

where z and y are governed by

$$\dot{z} = -\gamma|\dot{x} - \dot{y}|\, z\, |z|^{n-1} - \beta(\dot{x} - \dot{y})|z|^n + A(\dot{x} - \dot{y}) \qquad (3)$$

$$\dot{y} = \frac{1}{c_0 + c_1}\left[\alpha z + c_0\dot{x} + k_0(x - y)\right] \qquad (4)$$

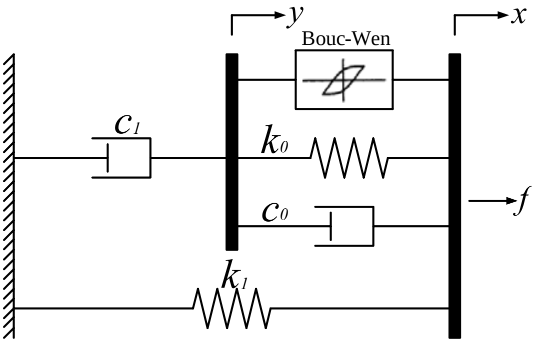

Figure 15 Phenomenological model of MR damper

Based on the data of the damping force versus the velocity of piston at various input voltages, the parameters (c_1, k_0, k_1, n, A, β and γ) of this model are identified as listed in Table 1 by a *Simulink* program. In which, the parameter values of α and c_0 vary nonlinearly with command voltages. The functions of α and c_0 are fitted as Eqns. (5) and (6) as follows:

$$\alpha = 2.3363\mathrm{v}^2 - 3.4209\mathrm{v} + 5000 \tag{5}$$

$$c_0 = 0.1794\mathrm{v}^2 - 2.0484\mathrm{v} + 2700 \tag{6}$$

Table 1: Constant parameters for phenomenal model of MR damper

Parameter	Value	Parameter	Value
C_1	50000 N s mm^{-1}	A	5
$k_0 = k_1$	1 N s mm^{-1}	β	1.6 mm^{-2}
n	2	γ	1.6 mm^{-2}

MATLAB and its' *Simulink* modeling environment are used to generate a numerical model of MR damper that accurately simulated the dynamics of the MR damper as measured during the performance tests. A comparison between the predicted responses and the corresponding experimental data is provided in figure 16 to figure 19. According to the comparison, it can be seen that the proposed model predicts the behavior of the MR damper very well.

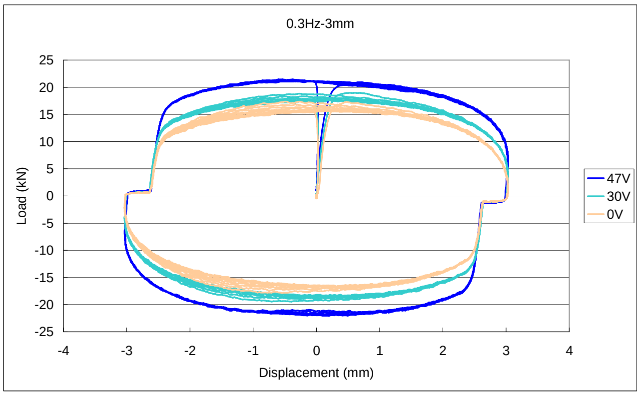

Figure 16 Force-displacement behaviors under a sinusoidal excitation at various input current

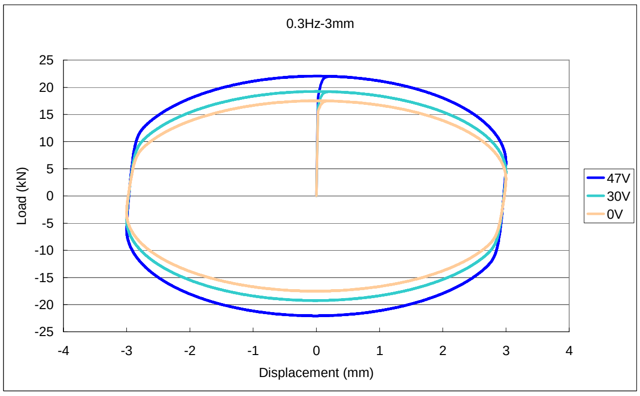

Figure 17 Predicted force-displacement behaviors using the numerical model proposed by Spencer

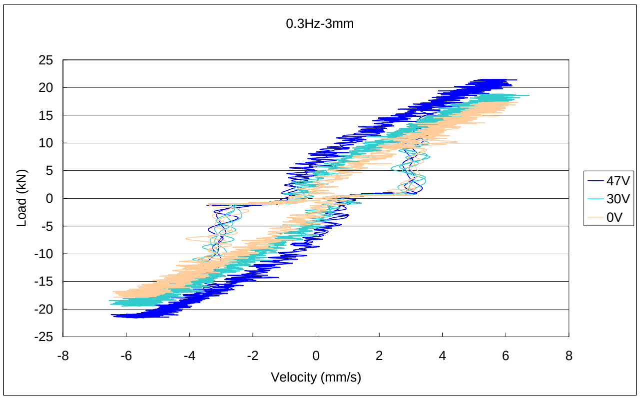

Figure 18 Force-velocity behaviors under a sinusoidal excitation at various input current

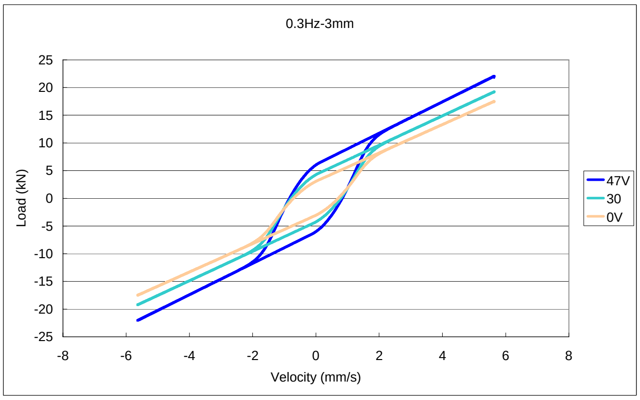

Figure 19 Predicted force- velocity behaviors using the numerical model proposed by Spencer

5. CONCLUSION

In this research, a fundamental understanding of the behavior of MR dampers has been developed through the modeling, design and experimental verification of two MR dampers. According to our experimental and theoretical studies, it could be concluded that:

- Based on the analysis of reduction effects and time histories, it can be seen that there is an improvement of the performance after notching inside the chamber. Therefore, it can be confirmed that the patterns of magnetic lines directly influence the thickness of MR fluid.
- Enhancement of MR damper depends not only on the manufacture of MR damper but also the velocity of excitation. Based on our experiments, the capacity of MR damper degrades while the velocity of piston rises.
- According to the comparison of numerical models with experimental data of MR damper, it can be seen that the behavior of our MR damper could be predicted through Spencer's model.

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