Comparison and experimental analysis of damping force model of MRF Damper

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Abstract. The fitting accuracy between the linear viscous ring damping force model and the non-linear sinusoidal viscous ring damping force model and the experimental data are analyzed. Analysis of the errors and relative errors. Point out the advantages and disadvantages of each model. Laid the foundation for practical application.

1. Introduction

Magnetorheological fluid (MRF) is a type of smart materials that rheological properties varies with the outside magnetic field changing. Control the strength of the external magnetic field, can change the rheological properties of magnetorheological fluid within milliseconds [1, 2]. This feature is useful for active and semi-active control dynamics [3, 4]. Especially in the middle and low frequency range (within 30Hz), it has been widely used in vibration isolation [5-8].

Many models are commonly used to describe the mechanical properties of magnetorheological fluids. Such as Bouc-Wen model [9], Double viscoelastic model [10], Herschel-Bulkley viscoelastic model [11], Bingham viscoelastic model [12], Double viscosity hysteresis model [13], Nonlinear hysteresis model [14] etc. These models either do not reflect the viscous dynamics well, or they have too many parameters and are not convenient for numerical processing.

The multi-ring groove MRF dampers was devised (has applied for national utility model patents: ZL 2004 2 0085234 2). The structure shown in Figure 1. By adjusting the size of the rectangular gap and the gap between the piston and the cylinder to meet different working needs. A linear viscous ring damping force model and a nonlinear sinusoidal viscous ring damping force model for magnetorheological dampers have been established. Comparing the fitting accuracy of the two models with the experimental data, Analysis of the advantages and disadvantages, it lays the foundation for the application and research of active and semi-active control.

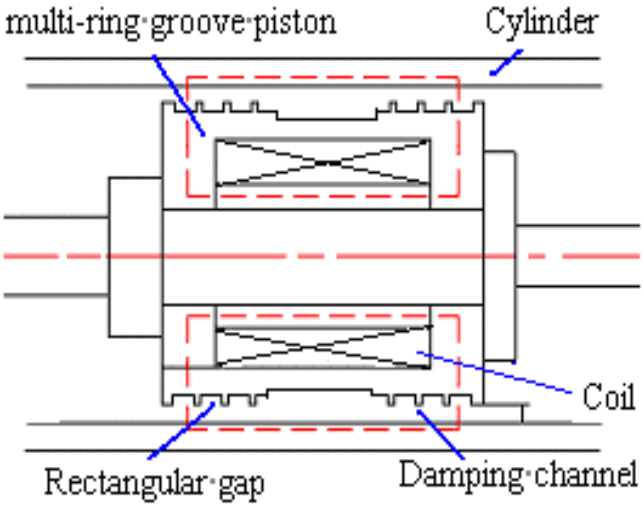

Figure 1. Multi-ring damper structure diagram

2. The model of damping force

2.1. Damping force

When the piston moves, the movement that MRF flow from one side of the piston to the other can be considered as a synthetic movement of differential pressure and shear flow, the damping force is:

$$\begin{aligned} F(t) &= F_p + F_s = \Delta p.A_p + L\pi D\tau \\ &= \frac{12\eta \mathrm{L}\, \mathrm{A_p}}{\pi \mathrm{D h^3}} A_p u(t) + \frac{3L\tau_y}{h} A_p \,\mathrm{sgn}[u(t)] + L\pi D\tau_y + \frac{L\pi D\mu}{h} u(t) \\ &= \left(\frac{12\eta \mathrm{L A_p^2}}{\pi D h^3} + \frac{L\pi D\eta}{h} \right) u(t) + \left(\frac{3LA_p}{h} + L\pi D \right) \tau_y \,\mathrm{sgn}[u(t)] \end{aligned} \tag{1}$$

Where, A_p is the pressure area of piston; $u(t)$ is the velocity of the piston relative to the cylinder; D is diameter of the piston; L is length of the piston; h is the gap; η is dynamic viscosity of the fluid; τ_y is the yield stress;

τ_y and η are relate with magnetic induction B:

$$\tau_y = f(B),\ \eta = g(B) \tag{2}$$

The Ampere of magnetic media [15] can be expressed as

$$\oint HdI = NI \tag{3}$$

So, τ_y and η can be expressed as a function of current I :

$$\tau_y = f'(I),\eta = g'(I) \tag{4}$$

2.2. Linear viscous ring damping force model

The linear viscous ring damping force model is shown in Figure 2. The points $(-u_1, F_1)$, $(-u_2, -F_2)$, $(u_1, -F_1)$ and (u_2, F_2) are the four vertices of the viscous ring.

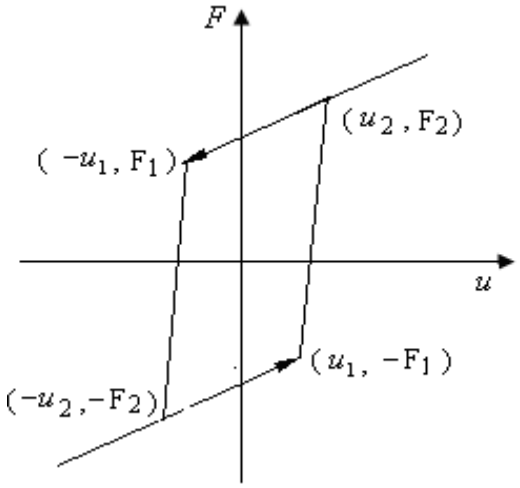

Figure 2. The linear viscous ring damping force model

Its expression is:

$$F = \begin{cases} cu - f & x < 0, -u_{\max} < u_2 < u_1, a > 0 \\ & or \quad x > 0, u_{\max} < u < u_2, a < 0 \\ ku + b_1 & x < 0, u_1 \le u \le u_2, a > 0 \\ cu + f & x < 0, u > u_2, a > 0 \\ & or \quad x > 0, u > -u_1, a < 0 \\ ku + b_2 & x > 0, -u_2 \le u \le -u_1, a < 0 \end{cases} \tag{5}$$

2.3. Nonlinear sinusoidal viscous ring damping force model

The nonlinear sinusoidal viscous ring damping force model is shown in Figure 3. The points A, B, C and D are the four vertices of the viscous ring.

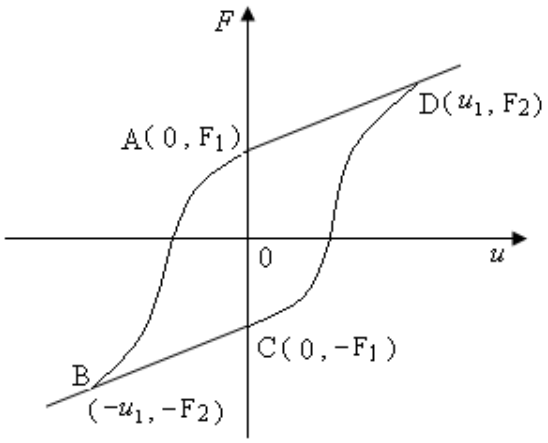

Figure 3. The non-linear sinusoidal viscous ring damping force model

In the picture, AD and BC are straight lines, and AB and CD are sinusoidal, AB tangent AD at point A, tangent BC at point B; CD tangent AD at point D, tangent BC at point C.

Its expression is:

$$F=\begin{cases} cu-f & x>0,-u_{\max}<u<0,a<0 \\ & or \quad x<0,-u_{\max}<u<-u_1,a>0 \\ A\sin(\omega u-\varphi)+B & x<0,0\le u\le u_1,a>0 \\ cu+f & x>0,u>0,a<0 \\ & or \quad x<0,u>u_1,a>0 \\ A\sin(\omega u+\varphi)-B & x>0,-u_1\le u\le 0,a<0 \end{cases} \tag{6}$$

In Equations (5) and (6), c is viscous damping coefficient, it relate with the structure and the MRF viscosity coefficient η; f is yield strength, it relate with the structure and the MRF yield stress τ_y; x, u and a representing displacement, velocity and acceleration of the piston.

3. Experimental procedure

Experiments are carried out on the hydraulic test rig incentive system (shown as Fig. 4), Slect the type of excitation signal through computer, Such as sine or cosine signal. Then t input the main parameters of signal and the current to start the experiment. The control system control the shock absorber according to the input signals, the displacement, force and acceleration parameters are recorded and feedback to the interactive computer.

The experiment uses a sinusoidal excitation signal, by changing the amplitude and frequency of the signal to control the excitation, by changing the current to control the strength of the MRF magnetic.

Figure 4. The diagram of the experimental equipment

4. Comparative analysis of two mechanical models and experimental data

The model data can be obtained by substituting the structural parameters, speed, current and other parameters of the damper into the two mechanical model formulas. A comparison image can be obtained, by placing the model data and the experimental data in a coordinate system.

Select 0.2A-3Hz-3mm experimental data, Shown in Figure 5. Model 1 is linear viscous ring damping force model, model 2 is nonlinear sinusoidal viscous ring damping force model. The image on the left

is the contrast of the displacement-damping force, and the image on the right is the contrast of the velocity-damping force image.

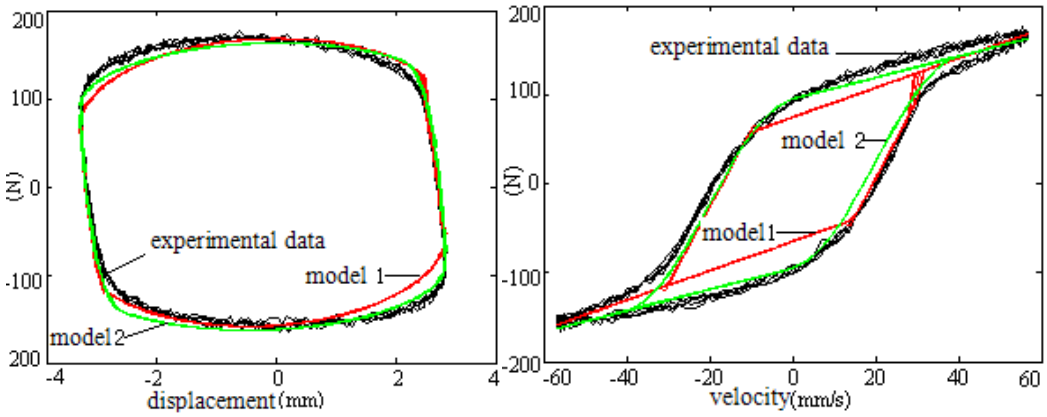

Figure 5. Comparison of the two model and experimental data, under current 0.2A, 3Hz-3mm

It can be seen that the two models can better reflect the damping force of the damper. But, in some areas, especially at the apex of the respective viscous rings of the two models, there is a large deviation. In order to better compare the fit of the two models with experimental data, calculate the errorand relative error between the two models and the experimental data. Shown in Figure 6. The left picture shows the error comparison chart, the right picture shows the relative error comparison chart.

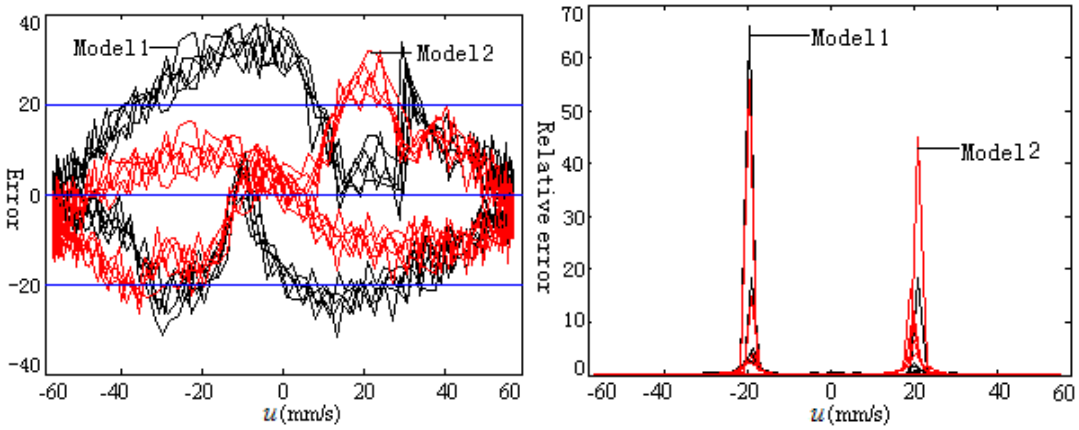

Figure 6. Comparison of the errors between two model and experimental data, under current 0.2A, 3Hz-3mm

As can be seen, the error is in the range of ±30N. The relative error is relatively large near the speed of ±20mm/s, this is not good for practical applications. The linear viscous ring damping force model and a nonlinear sinusoidal viscous ring damping force model fitting accuracy is higher in different regions.

5. Conclusion

The linear viscous ring damping force model have their own advantages. Segmentation can better reduce errors and improve fitting accuracy.

Acknowledgements

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