Comparison and experimental analysis of damping force model of MRF Damper

Jianhai Xue¹, Shixing Zhu²

¹School of Aircraft Maintenance Engineering, Guangzhou Civil Aviation College, Guangzhou 510403, China
²Graduate Department, Civil Aviation University of China, Tianjin 300300, China

xuejianhai@caac.net

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.
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:

\[
F(t) = F_p + F_s = \Delta p A_p + L \pi D \tau_y + \frac{L \pi d \mu}{h} \nu(t)
\]

\[
= \frac{12 \eta L A_p}{\pi D h^3} A_p u(t) + \frac{3 L \tau_y}{h} A_p \text{sgn}[u(t)] + L \pi D \tau_y + \frac{L \pi d \mu}{h} \nu(t)
\]

\[
= \left( \frac{12 \eta L A_p^2}{\pi D h^3} + \frac{L \pi D \eta}{h} \right) \nu(t) + \left( \frac{3L A_p}{h} + L \pi D \right) \tau_y \text{sgn}[u(t)]
\]

(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; \( \eta \) is dynamic viscosity of the fluid; \( \tau_y \) is the yield stress;

\( \tau_y \) and \( \eta \) are relate with magnetic induction \( B \):

\[
\tau_y = f(B), \quad \eta = g(B)
\]

(2)

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

\[
\oint H dl = NI
\]

(3)

So, \( \tau_y \) and \( \eta \) can be expressed as a function of current \( I \):

\[
\tau_y = f'(I), \quad \eta = g'(I)
\]

(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.

Its expression is:

\[
F = \begin{cases} 
  cu - f & x < 0, -u_\text{max} < u < u_1, a > 0 \\
  ku + b_1 & x < 0, u_1 \leq u \leq u_2, a > 0 \\
  cu + f & x < 0, u > u_2, a > 0 \\
  ku + b_2 & x > 0, -u_2 \leq u \leq -u_1, a < 0 \\
  & x > 0, u > -u_1, a < 0
\end{cases}
\]  \( (5) \)

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.

\[
F = \begin{cases} 
  cu - f & x < 0, -u_\text{max} < u < u_1, a > 0 \\
  ku + b_1 & x < 0, u_1 \leq u \leq u_2, a > 0 \\
  cu + f & x < 0, u > u_2, a > 0 \\
  ku + b_2 & x > 0, -u_2 \leq u \leq -u_1, a < 0 \\
  & x > 0, u > -u_1, a < 0
\end{cases}
\]  \( (5) \)
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:

\[
F = \begin{cases}
  cu - f & x > 0, -u_{\text{max}} < u < 0, a < 0 \\
  or & x < 0, -u_{\text{max}} < u < -u_{1}, a > 0 \\
  A \sin(\omega u - \varphi) + B & x < 0, 0 \leq u \leq u_{1}, a > 0 \\
  cu + f & x > 0, u > 0, a < 0 \\
  or & x < 0, u > u_{1}, a > 0 \\
  A \sin(\omega u + \varphi) - B & x > 0, -u_{1} \leq u \leq 0, a < 0
\end{cases}
\] (6)

In Equations (5) and (6), \(c\) is viscous damping coefficient, it relate with the structure and the MRF viscosity coefficient \(\eta\); \(f\) is yield strength, it relate with the structure and the MRF yield stress \(\tau_y\); \(x\), \(u\) 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.

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 error and 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.

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References

[1] Alexandridis A, Goadas J. Simplified model of the dynamics of magneto-rheological dampers [J]. Mechanics, 2005, 24 (2): 47 - 53.

[2] Yang Cuangqiang. Large-scale Magetorheological fluid Damper for Vibration Mitigation: Modeling, Testing and Control: University of Notre Dame, Indiana, USA, 2001.

[3] Gao Guosheng, Yang Shaopu, Guo Jingbo. Investigation and semi-active control of a lateral suspension systems to locomotive via MR damper [D]. Journal of Functional Materials, 2006 (5): 802 - 804.

[4] He Yadong, Huang Jinzhi, He Yuao, Study on Structural Intelligent Semi-Active Control Based on MR Damper [D]. Journal of Vibration Engineering, 2003, 16 (2): 198 – 202.

[5] Yang G, Spencer B F, Carlson J D, et al. Large-scale MR fluid dampers: modeling and dynamic performance considerations [J]. Engineering structures, 2002, 24 (3): 309 - 323.

[6] Gordaninejad F, Kelso S P. Magneto-rheological fluid shock absorbers for HMMWV [C]//SPIE’ 7th Annual International Symposium on Smart Structures and Materials. International Society for Optics and Photonics. Newport Beach, CA, 2000: 266 - 273.

[7] Carlson J D, Catanzarite D M, St Clair K A. Commercial magneto-rheological fluid devices [J]. International Journal of Modern Physics B, 1996, 10 (23/24): 2857 – 2865.

[8] Ha S H, Seong M, Choi Smilitary. vehicle suspension damper and disc spring [J]. 2013, 22 (6): 65006.

[9] Spencer BF, Dyke S J, Sainmk, et al. Phenomenological model for magnetorheological dampers. J of Eng Mech, 1997, 123 (3): 230 – 238.

[10] Yang Cuangqiang. Large-scale Magetorheological fluid Damper for Vibration Mitigation: Modeling, Testing and Control: University of Notre Dame, Indiana, USA, 2001.

[11] Li Yiyong, Pan Jiefeng Magnetic Damper FEM optimized design parameters [J]. Chongqing University, 2010, 33 (5), 35 - 40.

[12] Xiong Chao, Deng Jian Magnetorheological device design of key technologies [J]. Magnetic Materials and Devices, 2008, 39 (41), 37 - 40.

[13] Li pang, Gopalakrishna M. Kamath, Norman M. Wereley, Dynamic characterization and analysis of magnetorheogial dampers behavior, SPIE, 1998, 3227: 284 – 302.

[14] Weng Jiansheng, Fuzzy semi-active control of vehicle suspension system based on magnetorheological damper [D]. Journal of Nanjing University of Technology, 2001, 1 (1): 57 - 61.

[15] Guan Qiuyuan, Circuit. Higher Education Press, 2004.