Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(7) (2020) 491-494
DOI: 10.22060/mej.2018.14751.5930

Modeling of the Magnetorheological Damper with Optimization Approach for Magnetic Fluid Molecular Properties

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ABSTRACT: Magnetorheological damper, as one of the most widely used equipment in various industries, was firstly studied and optimized using a molecular properties analysis of operating magnetic fluid in it utilizing dissipative particle dynamics as molecular modeling method. By using modified Bouc-Wen model, hysteresis and damping force level have calculated in order to provide the required 10 N power requirement in micro-machines and after validation with experimental results presented in papers, the effect of molecular properties of magnetic fluid operating on it has investigated. Results of molecular modeling by dissipative particle dynamics method show that by increasing mass and diameter of magnetic particles, damping force increases, while by increasing number density of these particles and increasing mass of carrier fluid particles, damping force firstly increases and then decreases. Therefore, it is necessary to set optimal values. It is also observed that by decreasing the thickness of the surfactant layer at the surface of the magnetic particles, damping force increases. Finally, according to the obtained results, the optimal values of each studied parameters were determined to provide 10 N damping force with the least amount of energy consumed by damper and selected from commercial magnetic fluids 132-DG fluid as suitable magnetorheological fluid.

Review History:

Received: 25/07/2018
Revised: 23/10/2018
Accepted: 03/12/2018
Available Online: 09/12/2018

Keywords:

Magnetorheological damper
Dissipative particle dynamics modeling
Magnetic fluid
Damping force
Hysteresis

1. INTRODUCTION

Magnetorheological dampers are widely used in automotive, civil and aerospace applications as mechanical shock absorbers. Many studies are done to investigate the damping behavior of magnetorheological dampers. Different parametric and non-parametric models consist of Bingham viscoplastic model [1], Modified Bingham model [2], Bouc-Wen model [3] and corrected Dahl model [4]. Non-parametric models include polynomial model [5], neural network model [6] and fuzzy logic model [7]. In all of these studies, use of a molecular method to modeling damper has not been performed. Dissipative particle dynamics method is introduced as a new mesoscale modeling technique that can easily model particle dispersion. In this method, the base fluid molecules form clusters of particles in which the characteristic time of these clusters is proportional to dispersed particles and it is possible to simultaneously model the base fluid and dispersed particles. In this study, for the first time, modeling of a small-sized magnetorheological damper is developed by utilizing dissipative particle dynamics method. Validation of results is done by using experimental data which shows good conformity. The effect of molecular properties of different magnetic fluids are investigated and the optimum values of these properties are determined in order to reduce energy consumption of the electrical coil and find suitable operating point of magnetorheological damper. According to the experimental design of damper made by researchers and the structure of small-diameter dampers in micro-machines, damping force of 10 N was considered as the required damping force; therefore, suitable magnetorheological fluid was chosen to achieve this damping force with the least magnetic strength consumption.

2. MAGNETORHEOLOGICAL MODELING OF DAMPER

There are three types of forces apply on a particle: a repulsive conservative force F_{ij}^C exerted by the other particles; a dissipative force F_{ij}^C providing a viscous drag to the system; and a random or stochastic force F_{ij}^R, inducing the thermal motion of particles. Equation of particle motion i is written as follow:

$$m_d \frac{d\mathbf{V}_i}{dt} = \sum_{j(\neq i)} F_{ij}^C + \sum_{j(\neq i)} F_{ij}^D + \sum_{j(\neq i)} F_{ij}^R \tag{1}$$

$$F_{ij}^C = \alpha w_R(r_{ij}) e_{ij} \tag{2}$$

$$F_{ij}^R = \sigma w_R(r_{ij}) e_{ij} \zeta_{ij} \tag{3}$$

$$F_{ij}^D = -\gamma w_D(r_{ij})(e_{ij}.\mathbf{V}_{ij}) e_{ij} \tag{4}$$

First, in order to ensure the accuracy of the results, the magnetorheological damper constructed by Li et al. [8] is modeled and the results are compared with the available

*Corresponding author’s email: mmshahmardan@yahoo.com experimental data. Schematic view of constructed damper and its dimensions and size is shown in Fig. 1.

In molecular modeling, the bounce-back boundary condition is used to apply the no-slip condition on the walls. In order to calculate the damping force and determine the level of hysteresis in the modeling of small-scale magnetorheological damper, a computational model is needed which among the various computational models, the modified Bouc-Wen [9] is used.

Results of modeling are compared to the experimental data to validate dissipative particle dynamics modeling. Fig. 2 shows the effect of magnetic field strength change on damping force at different gap sizes, which shows good conformity.

3. RESULTS AND DISCUSSION

The results of modeling show by increasing magnetic field strength, the maximum force increased and the steady force decreases; while, with the increase in the density of magnetic particles, damping force first increased and then decrease to a constant value. Also, the maximum damping force is more in higher magnetic field strengths. To achieve considering damping force of 10 N, the number density of magnetic particle of 0.6 and magnetic strength of 40% are selected as optimal values and maintained during the modeling. In the following, the effect of the surfactant layer on the damping force is investigated. The modeling is performed in three thicknesses of the surfactant layer of 0.1, 0.6 and 0.9 is shown in Fig. 3. As shown, by increasing thickness of the surfactant layer, the magnetic fluid becomes more stable, but the excessive repulsive force caused the unstable particle chains and gradually lose its semi-solid state to the magnetic fluid, which leads to reduced optimal performance of damper.

Sensitivity analysis is performed by using MATLAB software in Fig. 4 shows that mass of dissipative particles has the most effect on the damping force.

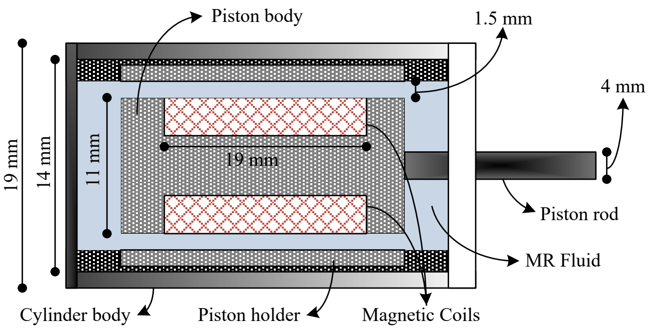

Fig. 1. Modeled damper by using dissipative particle dynamics method

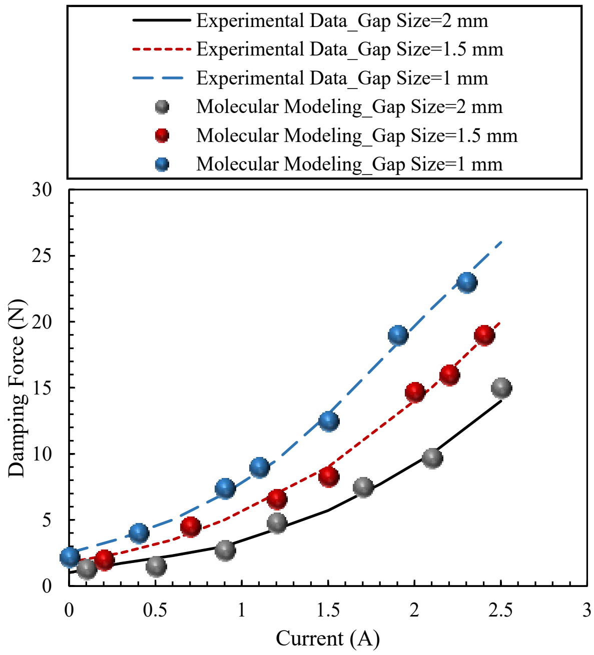

Fig. 2. Validation of results by using the experimental data for damping force changes versus electrical currents at different gap size [8]

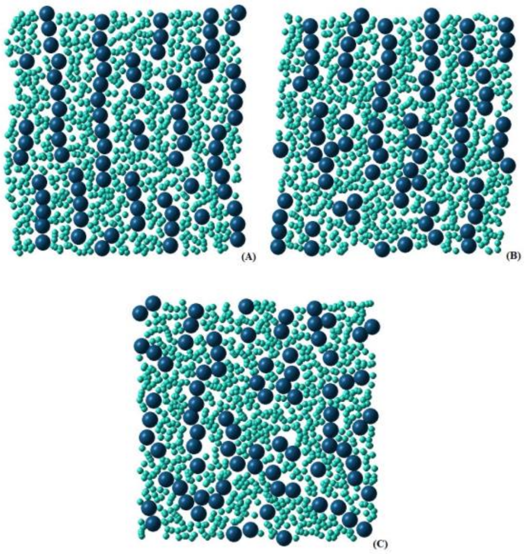

Fig. 3. Results of modeling at the different non-dimensional thickness of the surfactant layer (A) thickness of 0.1 (B) thickness of 0.6 (C) thickness of 0.9

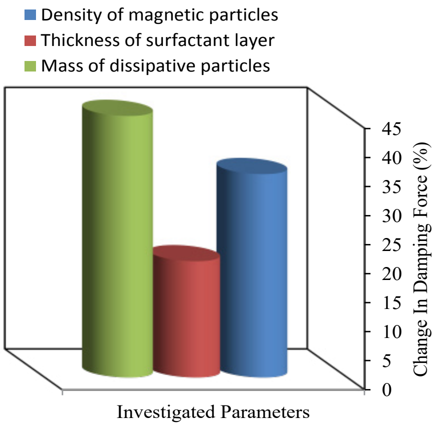

Fig. 4. Sensitivity analysis of different parameters on the damping force

4. CONCLUSION

The results of the modeling show that by increasing in diameter of magnetic particles, damping force increases; while, increasing in the thickness of the surfactant layer reduces damping force. To achieve considering damping force of 10 N, dimensionless diameter of magnetic particles and the non-dimensional thickness of the surfactant layer are 0.2 and 0.3, respectively. Under these conditions, the optimum number density of magnetic particles, mass of a magnetic and dissipative particle are considered to be 0.6, 0.05 and 0.1, respectively. Finally, to obtain the lowest energy consumption, according to the average power consumption of 40% of magnetic field strength, magnetic fluid of the 132-DG is selected as the appropriate fluid.

REFERENCES

[1] Y.B. Kazakov, N.A. Morozov, S.A. Nesterov, Nesterov calculation of force-velocity relationship of electromechanical magneto rheological fluid damper, *Vestnik IGEU*, 11(4) (2015) 17–22.

[2] D.R. Gamota, F.E. Filisko, Dynamic mechanical studies of electro rheological materials: moderate frequencies, *J. Rheol.* 35(3) (1991) 399–425.

[3] R. Stanway, J.L. Sproston, N.G. Stevens, Non-linear modelling of an electro-rheological vibration damper, *J. Electro stat.* 20 (2) (1987) 167–84.

[4] Y.F.Liu, J. Li, Z. M. Zhang, X. H. Hu, W. Zhang, experimental comparison of five friction models on the same test-bed of the micro stick-slip motion system, *J. Mech. Sci*., 32(6) (2015) 15-28.

[5] S.B. Choi, S.K. Lee, A hysteresis model for the field-dependent damping force of a magneto rheological damper. *Journal of Sound and Vibration*, 245(2) (2001) 375-383.

[6] D.H. Wang, W.H. Liao, Modeling and control of magneto rheological fluid dampers using neural networks, *Smart Materials and Structu*res, 14(1) (2005) 111-126.

[7] M. Sugeno, G.T. Kang, Structure identification of fuzzy model, *Fuzzy Sets and Systems*, 28(1) (1988) 15-33.

[8] J. Li, F. Li, Q. Tian, C. Zhou, C. Xiao, L. Huang, W. Wang, W. Zhu, Force-electrical characteristics of a novel mini-damper *Smart Mater. Struct.*, 25 (4) (2016) 105009-105016.

[9] F. Ikhouane, J.E. Hurtado, J. Rodellar, Variation of the hysteresis loop with the BoucWen model parameters, *Nonlinear Dynamics*, 48(4) (2007) 361–380.