Comparative study on the effect of single coil and multi coil magnetorheological damper through finite element analysis

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Abstract. Magnetorheological damper is vibration reducing system in which the magnetorheological fluid is the operating liquid which changes its behaviour with external stimulus by increasing the yield stress of fluid with the application of external magnetic field. Most of the vibration reducing equipment’s is operated with single coil, and in this paper, study of multi coil magnetorheological damper is discussed and compared with the single coil for its magnetic flux density of the applied currents is studied by dividing equal and unequal number of turns of the coil in multi coil unlike in single coil damper.

1. Introduction

Magnetorheological fluids are called smart fluids because of their variable flow characteristics in the presence of external applied current. Magnetic fluids are fluids whose properties change drastically in the presence of a magnetic field. Magnetorheological fluids (MR) were introduced by Robinow in 1948 and they consist of 20-40% of magnetic particles, suspended in a base fluid viz. castor, silicone oil, water etc. Different additives such as lithium grease, calcium grease, stearic acid (2-5%) etc are used to suspend magnetic particles in the base fluid to minimize the settling of particle.

Performance characterization of damper is based on the MR fluid B-H curve. Before designing of the damper, MR fluid with optimal concentrations of the constituents and the optimization of circuit of the MR damper is to be carried. Experimental investigation by steady state damping and comparing these with available models was studied (Snyder et al 1993). Experimental and numerical study on MR seat damper was carried out for damping characteristics of the fluid by using Bingham plastic model (Choi et al 2000). Magnetorheological damper with bypass holes was numerically and optimal number holes for better damping was studied (Sohn et al 2015). Analytical models for the characterization of the MR dampers for fluid flow was carried out and using simulations design parameters are also obtained (Chooi et al 2008). Mixed mode MR damper was characterized through finite element magnetics and also through experiment, which concludes that, combination of operating modes gives more damping compared to single mode operation (Iryani et al. 2014). MR damper with outer multi coil gives us larger damping force compared with normal dampers was studied (Liu et al. 2018). Optimization of double coil MR damper parameters through Ansys parametric design language and experimental Ansys was also carried for different objectives (Hu et al. 2016). Validation of finite element analysis of MR damper with the experimental results was studied for better design parameters (Mangal and Kumar 2014). Comparison of electrorheological fluids and magnetorheological fluids for optimal design of MR dampers was studied (Choi et al 2014, Gavin et al 2014). Experimental investigation and control of magnetorheological dampers was carried out and reasonable results were obtained for further design strategies (Milecki 2001). Review of MR dampers for various applications and current state of
art was discussed. Analysis of the MR dampers using eccentric and concentric gap was carried experimentally and compared (Zhu et al 2013).

2. Nomenclature and Materials used in FE analysis
Generally, MR damper consists of piston cylinder arrangement where movement of the piston might be horizontal or vertical. In our case piston movement is vertical. The cylinder cavity is filled with MR fluid which is agitated by applying external field which increases restriction by increasing the yield stress to the movement of the piston and this restriction is applied to various engineering application. The materials selected is given in the table 1. From the literature study shear gap, shear length and number of turns coil is selected and table 2 gives the effective dimensions. Figure 1 and figure 2 shows single coil and multi coil MR dampers and B-H curves for material and MR fluid.

![Figure 1. Line diagram of (a) Single coil and (b) Multi coil MR damper respectively](image)

![Figure 2. B-H curve for SA1018 and MRF-132DG](image)

| Parts             | Material used            |
|-------------------|--------------------------|
| Outer cylinder    | SA1018                   |
| Piston-rod        | Aluminium alloy          |
| Piston-core       | SA1018 + copper coil     |
| MR fluid          | Lord-132DG               |
3. Finite Element analysis

The damping force which is the output of the MR damper depends on the dimensions of electric circuit used for the piston core. When the external power is passed to the electrical circuit, magnetic flux is produced in shear gap region. The flux lines induced through the effective length varies the yield strength of the MRF. The parameters which plays an important role are shear flow gap, effective length of shear, material selected for damper fabrication. The damper performance is changed when the dimensional parameters of the electrical circuit are varied. Under off state, the energy generated in the MR damper is relied on the original MR fluid viscosity. To increase the performance of the damper two coils i.e. multi coil and single coil dampers are selected and modelled for FE analysis. Before going on to the actual damper fabrication the effect of number of turns of the coil, shear gap, pole length and applied currents studied on both coil arrangements. In this article, FE analysis is done for single coil and multi coil arrangement MR damper models for better magnetic flux density is analyzed.

4. Results and Discussion

By using the multi coil damper, magnetic flux density obtained in the flow gap is approximately 0.12 tesla more compared to single coil MR damper for equal divisions of number turns of coil and if the divisions is same on either pistons as that of the single coil, the flux density obtained is higher compared to the both the single and multi-coil with equal number of turns as shown in the figure 3 and figure 4. The decrease in the flux density with increase in the flow gap and pole length as shown in figure 5. When the field is applied to multi coil damper there is a extra shear length is available which increases the contact between the shear length and MR fluid in the flow gap that gives additional resistance for the movement of the piston in turn it is damping force which is applicable in more damping. The optimal design has to be obtained for the further experimentation on the magnetorheological dampers. Figure 6(a-f) shows comparison of magnetic flux densities of all the three models.
Figure 3. (a) Flux density of the applied field and (b) intensity of applied magnetic field of single coil MR damper for 4mm(L)-0.5mm(g) and 6mm(L)-2mm(g) respectively

Figure 4: (a) Flux density of the applied field and (b) intensity of the applied magnetic field for multi coil MR damper for 4mm(L)-0.5mm(g) and 6mm(L)-2mm(g)
Figure 5. Current vs Flux density of (a) single coil and (b-c) multi coil damper of all the models. for 200, (100+100) and (200+200) turns respectively.
### Model 1 (2Amps)

| Current and number of turns | Upper pole length | Middle pole length | Lower pole length |
|-----------------------------|-------------------|--------------------|-------------------|
| 2A(200) turns               | 0.99083           | 0.49847            | 0.66244           |
| 2A(100+100) turns           | 0.74097           | 0.48495            | 0.64755           |
| 2A(200+200) turns           | 0.99552           |                    |                   |

### Model-2 (0.5Amps)

| Current and number of turns | Upper pole length | Middle pole length | Lower pole length |
|-----------------------------|-------------------|--------------------|-------------------|
| 0.5A                       | 0.28132           | 0.11642            | 0.55808           |
| 2A(200) turns              | 0.27315           |                    |                   |
| 2A(100+100) turns          | 0.15325           | 0.11048            |                   |
| 2A(200+200) turns          | 0.20322           | 0.37716            | 0.20957           |

### Model-2 (2Amps)

| Current and number of turns | Upper pole length | Middle pole length | Lower pole length |
|-----------------------------|-------------------|--------------------|-------------------|
| 2A(200) turns               | 0.992410.98754    | 0.45215            | 0.55808           |
| 2A(100+100) turns           | 0.33105           | 0.32354            | 0.56188           |
| 2A(200+200) turns           |                    |                    | 0.7379            |
Figure 6(a-f). Comparison of flux density of model-1, model-2 and model-3 for single coil and multi coil MR damper at 0.5A and 2A

5. Conclusion

- The multi coil MR damper gives the better magnetic flux density when compared to the single coil MR damper, when the multi coil turns is greater than single coil turns. By splitting equal turns in the multi coil piston gives 21.5% lesser flux density of the applied magnetic field and by splitting the number of coils turns greater than that of the single coil turns there is 53.54% rise in the magnetic flux density of the applied magnetic field.
- The performance of MR damper decreases with simultaneous increase in the flow gap and shear length for both single coil and multi coil MR damper. Based on the requirement of our application, the MR damper parameters has to be optimised before going on to actual fabrication and experimentation.

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References

[1] Seung-Bok Choi, Moo-Ho Nam and Byung-kyu lee 2000. *Journal of Intelligent Material Systems and Structures*.

[2] Choi, Young-tai, and Norman M Wereley. 2015, *Advances in Mechanical Engineering*.

[3] Weng WChooi, and S Olutunde Oyadiji 2008. *Computers and Structures* 86, 473–482 86: 473–82.

[4] Henri Gavin, Jesse Hoagg, and Mark Dobossy 2001. *Proceedings U.S.-Japan workshop on Smart Structures for Improved Seismic Performance in Urban Regions*, 225-236.

[5] Guoliang Hu, Fengshuo Liu, Zheng Xie, and Ming Xu 2016. *Shock and Vibration*, Volume2016

[6] Izyan Iryani Mohd Yazid, Saiful Amri Mazlan, Takehito Kikuchi, Hairi Zamzuri, Fitrian Imaduddin, *Journal of Materials and Design* 54: 87–95.

[7] Shaogang Liu, Lifeng Feng, Dan Zhao, He Huang, Xinxin Shi, Lu Chen and Junxiang Jiang, 2018. *Smart Materials and Structures* 27(11).

[8] S.K.MangalandAshwaniKumar2014. *Chinese Journal of Engineering* Volume 2014.

[9] Andrzej Milecki 2001. *International Journal of Machine tools and Manufacture* 41(3) 379–91.

[10] Rebecca ASnyder, Gopalakrishna M Kamath and Norman M Wereey 2001. *AIAA Journal 39*(7): 1240-1253.

[11] Jung Woo Sohn, Jong-Seok Oh and Seung-Bok Choi 2015, *Smart Mater. Struct.* 24 035013 (13pp)

[12] Zhu, Xiaocong, Xingjian Jing, and Li Cheng. 2013. *Journal of Intelligent Material Systems and Structures*. 