ijcrr
Vol 04 issue 05
Category: Research
Received on:08/12/11
Revised on:22/12/11
Accepted on:10/01/12

A STUDY ON MAGNETORHEOLOGICAL FLUID (MRF) DAMPER

D.V.A. Rama Sastry[1], K.V.Ramana[2], N.Mohan Rao[3]

[1]Department of Mechanical Engineering, KL University, Vaddeswaram, Guntur
[2]R&D, KL University, Vaddeswaram, Guntur
[3]Department of Mechanical Engineering, JNTUCEK, JNT University, Kakinada

E-mail of Corresponding Author: dvarsastry@gmail.com

ABSTRACT

Vibration signals indicate machine's health. In most of the cases, it stipulates the requirement of bringing down vibration intensity to operational limit. Researchers are focusing over different types of vibration isolators and their optimization in terms of space occupancy, weight, cost and reliability. In this paper, an attempt has been made to introduce the basic concepts of Magnetorheological Fluids (MRF) which can be used as a semiactive vibration isolator, for the beginners and researchers. The scope of MR fluids in future, problems are also presented.

Keywords: Semi active vibration isolator, Magnetorheological fluid, Magnetorheological fluid damper

INTRODUCTION

Vibrations in a machine are unavoidable due to characterization of kinetic energy. Efforts are to be made at the design stage to reduce the intensity of vibration to extend the life of the machine. Vibration isolation is the procedure by which the undesirable effects of vibration are reduced.

The need for vibration isolation is becoming increasingly important for precision structures and sensitive high technology equipment. Also it is becoming vital to design more reliable devices with a higher bandwidth, smaller size, and lower power requirement.

Semi-active control has recently been an area of much interest because of its potential to provide the adaptability of active devices without requiring a significant external power supply for actuators. Semi-active control has been developed as a compromise between passive and active control. Instead of opposing a primary disturbance as is the case with active control, semi-active control scheme applies a secondary force to the system. A semi-active control system cannot provide energy to a system comprising the structure and actuator, but it can achieve favorable results by altering the properties of the system, such as stiffness and damping [1].

The close attention received in this area in recent years can be attributed to the fact that semi-active control devices offer the adaptability of active control devices without requiring the associated large power sources. In addition, as stated earlier, semi-active control devices do not have the potential to destabilize (in the bounded input/bounded output sense) the structural system. Extensive studies have indicated that appropriately implemented semi-active systems perform significantly better than passive devices and have the potential to achieve the majority of the performance of fully active systems, thus allowing for the possibility of effective response reduction during a wide array of dynamic loading conditions [2-5].

Magnetorheological fluids and their characteristics

Recently, a very attractive and effective semi-active system featuring Magnetorheological Fluid (MRF) dampers has been proposed by many investigators [6-8]. Magnetorheological is a branch of Rheology that deals with the flow and deformation of the materials under an applied magnetic field. Magnetorheological (MR) fluids are suspensions of non-colloidal (0.05-10 μm), multi-domain, and magnetically soft particles in organic or aqueous liquids [2]. They are able to change reversibly from free-flowing, linear viscous liquids to semi-solids having controllable yield strength under a magnetic field [9]. Their apparent viscosity changes significantly (10^5−10^6 times) within a few milliseconds, when the magnetic field is applied. The inert-particle forces originating from the magnetic interactions lead to a material with higher apparent viscosity. This dipolar interaction is responsible for the chain like formation of the particles in the direction of the field as shown in Fig. 1[9]. Particles held together by magnetic field and the chains of the particles resist to a certain level of shear stress without breaking, which make them behave like a solid. This phenomenon develops a yield stress which increases as the magnitude of the applied magnetic field increases [10]. One of the advantages of MR fluids is the higher yield stress value. Low voltage power supplies for MR fluids [11] and relative temperature stability between –40°C and +150°C make them more attractive materials for vibration isolation. In MR fluids, materials with lowest coercivity and highest saturation magnetization are preferred, because as soon as the field is taken off, the MR fluid should come to its demagnetized state in milliseconds. Due to its low coercivity and high saturation magnetization, high purity carbonyl iron powder appears to be the main magnetic phase of most practical MR fluid compositions. MR fluids have been prepared based on ferromagnetic materials such as manganese-zinc ferrite and nickel zinc ferrite of an average size of 2 μm.

The robustness and the simple mechanical design of Magnetorheological (MR) dampers make them an obvious choice for a semi-active control device. They require minimal power while delivering high forces suitable for fullscale applications. They are fail-safe since, they behave as passive devices in case of a power loss [13].

MR devices can be divided into three groups of operational modes or a combination of the three based on the design of the device [10, 12]. In the valve/shear mode, of the two surfaces that are in contact with the MR fluid, one surface moves relative to the fluid. This relative motion creates a shear stress in the fluid. The shear strength of the fluid may be varied by applying different levels of magnetic field. In the direct shear/flow mode, the fluid is pressurized to flow between two surfaces which are stationary. The flow rate and the pressure of the fluid may be adjusted by varying the magnetic field. In the squeeze film mode, two parallel surfaces squeeze the fluid in between and the motion of the fluid is perpendicular to that of the surfaces. The applied magnetic field determines the force needed to squeeze the fluid and also the speed of the parallel surfaces during the squeezing motion[14].

A magnetic circuit is necessary to induce the changes in the viscosity of the MR fluid. By using Kirchoff's Law of magnetic circuits, the necessary number of amp-turns (*NI*) is

$$NI=\sum H_i L_i = H_f g + H_s L \text{ ....(1)}$$

where H_f and H_s are the magnetic field intensity of the fluid and the steel, respectively, g is the length of the gap where the fluid flows, and L is the total length of the steel path. From equation (1), it is clear that, to increase the total magnetic field intensity, the number of amp-turns have to be kept at a maximum while minimizing the length of the fluid gap and the steel path. However, sufficient cross-section of steel must be maintained such that the magnetic field intensity in the steel is very low. Also, too small a fluid gap would cause the damping force to be too high when no magnetic field is applied. The magnetic circuit typically uses low carbon steel, which has a high magnetic permeability and saturation. This steel effectively directs magnetic flux into the fluid gap.

Properties of commercial MR fluids

Basic composition and density of four commercial MR fluids are given in Table 1 and ranking of fluids on the basis of various material properties are given in Table 2[10]. The MR fluids within the pre-yield region exhibit viscoelastic properties and these are important in understanding MR suspensions, especially for vibration damping applications.

MR damper

Several different designs of MR dampers have been built and tested in the past. The first of these designs is the bypass damper as shown in Fig.3 (a), where the bypass flow occurs outside the cylinder and an electromagnet applies a magnetic field to the bypass duct [15]. While this design has a clear advantage that the MR fluid is not directly affected by the heat build-up in the electromagnet, the presence of the bypass duct makes it a less compact design. In another design, the electromagnet is inside the cylinder and the MR fluid passes through an annular gap around the electromagnet as shown in Fig. 3(b). This design uses an accumulator to make up for the volume of fluid displaced by the piston rod which is going into the damper[16]. A variant to this is a twin tube MR damper that has two fluid reservoirs, one inside of the other, as shown in Fig. 3(c). In this configuration, the damper has an inner and outer housing. The inner housing guides the piston rod assembly, in exactly the same manner as in a mono tube damper. The volume enclosed by the inner housing is referred to as the inner reservoir. Likewise, the volume that is defined by the space between the inner housing and the outer housing is referred to as the outer reservoir. The inner reservoir is filled with MR fluid so that no air pockets exist.

However, most of these dampers were intended for large-scale applications such as vibration isolation of buildings and bridges. A linear, double-shaft MR damper with the electromagnet placed inside the cylinder is suitable for small-scale applications and is intended for use with parallel platform mechanisms where a damper will adjust the damping in each leg connector of the mechanism.The MR damper utilizes the unique properties of the MR fluid. In this design, the MR fluid flows through the annular gap between the housing and the magnetic body as seen in Fig. 4. The damper operates in a combination of valve and direct shear modes. A magnetic field is created along this gap through the use of a coil which is wrapped around the magnetic body. When the magnetic field is applied, the viscosity of the magnetorheological fluid increases in a matter of milliseconds. The field causes a resistance to the flow of fluid between the two reservoirs. This way, the damping coefficient of the damper is adjusted by feeding back a conditioned sensor signal to the coil. Double-ended MR dampers have been used for bicycle applications [17] gun recoil applications [18], commercial applications [19-21], and for controlling building sway motion caused by wind gusts and earthquakes [22].

Problems with MR dampers and future scope

a) Large size MR dampers limit their use in marine applications due to limited space especially in submarines. Design of MR dampers small in size needs to be further researched.
b) Non-linear behavior of MR dampers makes it difficult to devise control strategies to control the vibration. Studies on this are done by Mao *et al.* [23]. This effect further needs to be researched.
c) Control strategies further need to be researched to control the vibration in varying conditions. Jansen and Dyke [24] had done some studies on this area.
d) Reliability and maintainability should be further investigated to ensure success.
e) Implementation of MR dampers in real structures. Some studies were done on applications of MR damper in automobile industry [25-31], train suspension system [32], seismic protection of buildings [33-35], cable-stayed bridges [36].
f) To increase the self-sufficiency of the damping system, investigations into development of a self-powered MR damper should be pursued.

CONCLUSION

The ability to tune the rheological properties of Magnetorheological (MR) fluids has led to vast research opportunities in the field of mechanical vibration control. Such opportunities have directed researchers to explore such topics as semiactive or adaptive vibration control; a very promising and important application in the attenuation of vibrations. Commercial applications are clearly expanding and in future, will probably be driven by equipment manufacturers looking to add value to their products through the introduction of smart fluids. Three areas where significant developments might be expected can be – automotive, civil and aerospace engineering.

ACKNOWLEDGEMENTS

Authors acknowledge the immense help received from the scholars whose articles are cited and included in references of this manuscript. The authors are also grateful to authors / editors / publishers of all those articles, journals and books from where the literature for this article has been reviewed and discussed.

REFERENCES

1. S. J. Dyke, B. F. Spencer, M. K. Sain, and J. D. Carlson: Experimental verification of semi-Active structural control strategies using acceleration feedback, Proc. 3rd International Conference on Motion and Vibration Control, Japan, 1996, Vol. III, pp. 291-296.
2. Hoogterp, F. B., Saxon, N. L., Schihl, P. J., "Semi-active Suspension for Military Vehicles,"Society of Automotive Engineering International Congress and Exposition, Detroit, Michigan, March, 1993.
3. Karnopp, D., Crosby, M.J., "System for Controlling the Transmission of Energy Between Spaced Members," US Patent No. 3,807,678, 1974.
4. Karnopp, D., Crosby, M. J., Harwood, R. A., " Vibration control using semi-active force generator," Journal of Engineering for Industry, Transactions of the ASME, May 1974, v 96 Ser B, n 2,pp.619-626.
5. Miller, L. R., Nobles, C. M., "The design and development of semi-active suspensions for a military tank," Society of Automotive Engineering Future Transportation Technology

Conference and Exposition, San Francisco, California, August, 1988.

6. Sassi, S., Cherif, K., Mezghani, L., Thomas, M., Kotrane, A.: An innovative magnetorheological damper for automotive suspension: from design to experimental characterization. Smart Mater. Struct. 2005, Vol. 14, pp.811–822
7. Lam, A.H.-F., Liao, W.-H.: Semi-active control of automotive suspension systems with magneto-rheological dampers. Int. J. Veh. Des. 2003, Vol. 33(1/2/3),pp.50–75.
8. Nguyen, Q.H., Choi, S.B.: Optimal design of MR shock absorber and application to vehicle suspension. Smart Mater. Struct. 18(3), 035012 (2009)
9. Chen K C, Yeh C S, A mixture model for magneto-rheological materials, Continuum Mech Thermodyn, 2002, 15, pp.485−510.
10. M. R. Jolly, J. W. Bender and J. D. Carlson, Properties and Applications of Commercial Magnetorheological Fluids, Journal of Intelligent Material Systems and Structures, 1999, Vol. 10, No. 1, pp. 5-13.
11. Ginder J M, Davis L C, Elie L D. Rheology of magnetorheological fluids: Models and measurements , Proceedings of the fifth International Conference on ER Fluids and MR Suspensions. Sheffield, UK, 1996.
12. R. Bolter and H. Janocha, Design Rules for MR Fluid Actuators in Different Working Modes, in proceedings of the SPIE, Symposium on Smart Structures and Materials, 1997, Vol. 3045, pp.148-159.
13. M.D. Symans and M.C. Constantinou: Experimental testing and analytical modeling of semi-active fluid dampers for seismic protection. Journal of Intelligent Material Systems and Structures, 1997, Vol. 8, No. 8 pp. 644-657.
14. M. Yalcintas: Magnetorheological fluid based torque transmission clutches, Proc. 9th International Offshore and Polar Engineering Conference, Brest, France, 1999, pp.563-569.
15. H. Sodeyama, K. Sunakoda, H. Fujitani, S. Soda, N. Iwata, and K. Hata: Dynamic tests and simulation of magneto-rheological dampers. Computer-Aided Civil and Infrastructure Engineering, January 2003, vol. 18, No.1, pp. 45-57.
16. R.A. Snyder, G.M. Kamath, and N.M. Wereley: Characterization and analysis of magnetorheological damper behavior under sinusoidal loading. AIAA Journal, 2001, Vol. 39, No.7, pp. 1240-1253.
17. Ahmadian, M.: Design and development of magnetorheological dampers for bicycle suspensions. American Society of Mechanical Engineers, Dynamic Systems & Control Division Publication, DSC, 1999, Vol. 67, pp.737-741
18. Ahmadian. M., J. C. Poynor, J. M. Gooch: Application of magneto-rheological dampers for controlling shock loading. American Society of Mechanical Engineers, Dynamic Systems & Control Division Publication, DSC, 1999, Vol.67, pp. 731-735.
19. Carlson D, D. M. Catanzarite and K. A. St. Clair: Commercial magneto-rheological fluid devices, Lord Corporation, 2001.
20. Carlson, J. D., W. Matthis, and J. R. Toscano.: Smart prosthetics based on magneto-rheological fluids, Proc. SPIE 8th Annual Symposium on Smart Structures, Newport Beach, CA, March 2001, pp.308-316

21. Designing with MR fluids, Lord Corporation Engineering note, Thomas Lord Research Center, Cary, NC. 1999.
22. Dyke, S. J., Spencer, B. F. Jr., Sain, M. K., and Carlson, J. D: Seismic response reduction using magnetorheological dampers, Proc. 13th Triennial World Congress, International Federation of Automatic Control, San Francisco, CA, June/July, 1996. Vol. L, pp. 145–150.
23. Mao, M., Choi, Y.-T., and Wereley, N. M: Effective Design Strategy for a Magneto-Rheological Damper Using a Nonlinear Flow Model. Smart Structures and Materials 2005: Damping and Isolation, SPIE, Vol. 5760, pp. 446-455.
24. Laura M. Jansen and Shirley J. Dyke: Semi-Active Control Strategies for MR Dampers: A Comparative Study. ASCE Journal of Engineering Mechanics, 2000, Vol. 126, No. 8, pp. 795–803.
25. Wang E R, Ma X Q, Subhash R, Su C Y: Force tracking control of vehicle vibration with MR-dampers, Proc. 2005 IEEE International Symposium on Intelligent Control, Limassol, 2005.pp.995-1000.
26. Choi S B, Lee B K, Hong S R: Control and response characteristics of a magetorheological fluid damper for passenger vehicle. Journal of Smart Structure and Integrated Systems, 2000, Vol.3 (2), pp.438–443.
27. Lai C Y, Liao W H.: Vibration control of a suspension system via a magnetorheological fluid damper. Journal of Vibration and Control, 2002, Vol. 8(4), pp.527–547.
28. Wang E R, Ma X Q: Semi-active control for vibration attenuation of vehicle suspension with symmetry MR-damper. Journal of Southeast University, 2003, Vol. 19(3), pp.264–269.
29. Hiu F L, Liao W H: Semi-active control of automotive suspension systems with magnetorheological dampers, Hong Kong: The Chinese University of Hong Kong, Shatin, 1999.
30. Lai, C. Y. and Liao, W. H.: Vibration control of a suspension system via a manetorheological fluid damper. Journal of Vibration and Control, 2002, Vol. 8, pp.527–547.
31. Kim C, Ro P I: A sliding mode controller for vehicle active suspension systems with non-linearities, Journal of Automobile Engineering, 1999, Vol.212, pp.79-92.
32. Liao W H, Wang D H.: Semi-active vibration control of train suspension systems via magnetorheological dampers. The Chinese University of Hong Kong, 1999.
33. Lin P Y, Roschke P N, Loh C H, Cheng C P.: Hybrid controlled base isolation system with semi-active magnetorheological damper and rolling pendulum system. Taipei: National Center for Research on Earthquake Engineering, 1999.
34. Johnson E A, Ramallo J C, Spencer Jr B F, Sain M K: Intelligent base isolation systems, Proc. Second World Conference on Structural Control, Kyoto, 1999, pp.367-376.
35. Li H N, Chang Z G, Song G B: Studies on structural vibration control with MR dampers using μGA. Proc. 2004 American Control Conference, Massachusetts, 2004, pp.6478-6482
36. Wu W J, Cai C S.: Experimental study of magnetorheological dampers and application to cable vibration control. Journal of Vibration & Control, 2006, Vol.12, pp.67-82.

Appendix

Table.1 Basic composition and density of four commercial MR fluids *[2]*

Commercial MR Fluid	Percent iron by volume	Carrier fluid	Density per $g.ml^{-1}$
MRX-126PD	26	Hydrocarbon oil	2.66
MRX-140ND	40	Hydrocarbon oil	3.64
MRX-242AS	42	Water	3.88
MRX-336AG	36	Silicone oil	3.47

Table. 2 Ranking of fluids on the basis of various material properties, with '1' being best and '4' being worst [2]

MR Fluid	τ^2/η	$\tau^2/\eta\rho$	τ/BH	Initial Settling	Friction Coefficient	Temperature range
MRX-126PD	2	2	4	4	1	3
MRX-140ND	3	3	2	3	2	2
MRX-242AS	1	1	1	2	3	4
MRX-336AG	4	4	3	1	4	1

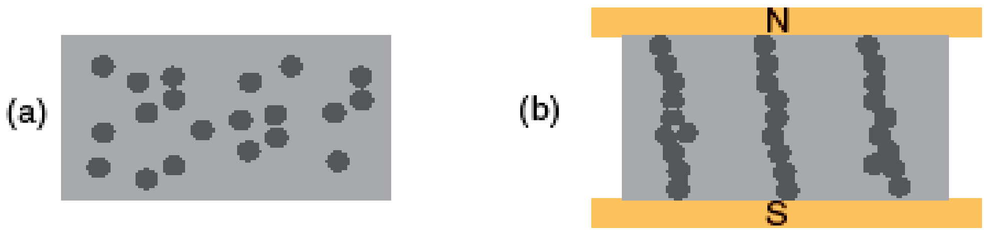

Fig. 1. Magnetorheological fluid: (a) no magnetic field and (b) with magnetic field

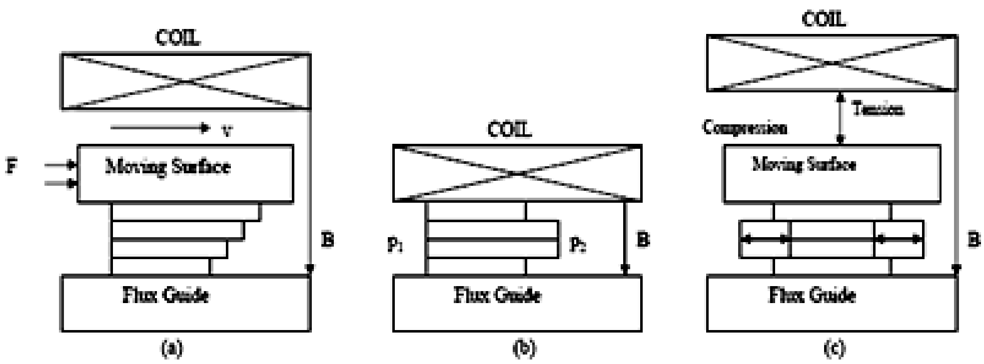

Fig.2. Three working modes of a MR fluid (a) Shear, (b) flow, and (c) squeeze. B is the magnetic flux direction.

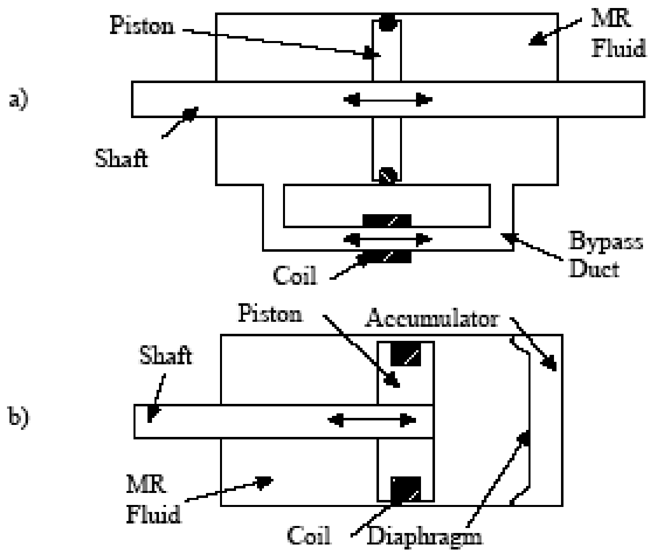

Fig.3. Schematic of (a) MR fluid bypass damper
(b) MR fluid damper with accumulator

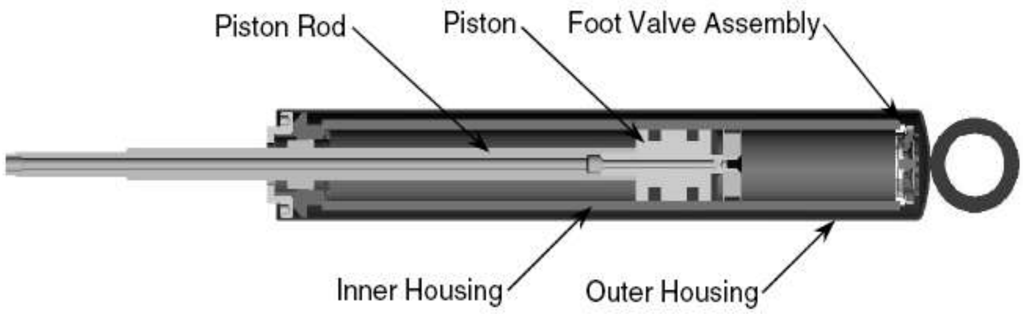

Fig. 3(c) Twin tube MR damper

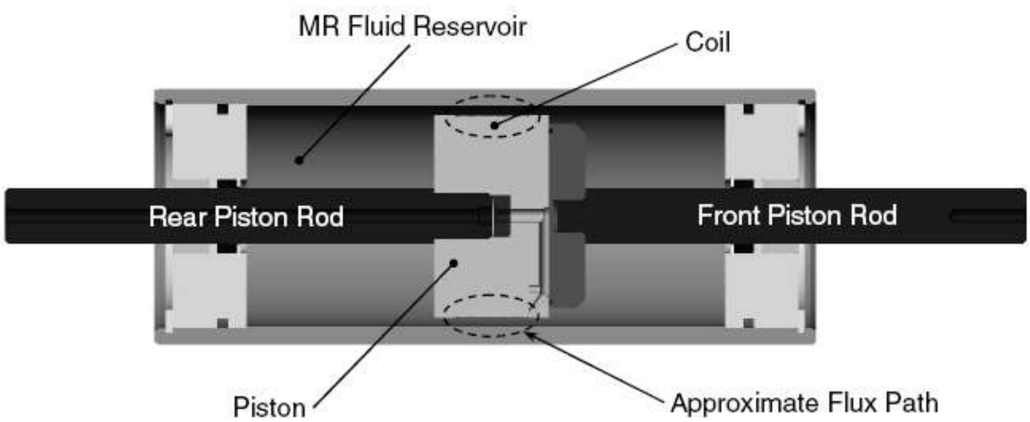

Fig.4 Double-shaft MR damper