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Study on the Influence of Synthesized Nano Ferrite Powder and Micron Ferrite Powder on Damping of a Single Degree of Freedom System

Easu DAKSHNAMOORTHY*, Siddharthan ARJUNAN, Amrutha RADHAKRISHNAN***, Andal GOPAL******

**Department of Mechanical Engineering, KCG College of Technology, Chennai, India, 600045, E-mail: easu.mech@kcgcollege.com*

***Department of Production Technology, Madras Institute of Technology, Chennai, India, 600044, E-mail: sidharth@annauniv.edu*

****Department of Physics, KCG College of Technology, Chennai, India, 600045, E-mail: amrutha@kcgcollege.com*

*****Department of Chemistry, KCG College of Technology, Chennai, India, 600045, E-mail: andal.che@kcgcollege.co*

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Nomenclature

C – damping coefficient of MRF; *ξ – damping ratio*; *A – ampere*; *Hz – hertz.*

1. Introduction

Nowadays, the automobile industry faces stiff competition to provide an excellent comfort, aesthetics, and performance of the vehicle on the road to attract the customers. Road conditions, unequal distribution of loads on the vehicle and forces during the dynamic conditions affect the performance of the vehicle. Conventional suspension systems use springs and dampers whose parameters are unaltered and it is possible by adding advanced suspension elements in parallel or in series with the conventional elements. Magnetorheological Fluid damper (MRF) and electrorheological fluid damper are the elements of semi active suspension systems that provide forces to suppress the vibration. MRF is gaining potential applications in various fields of engineering and often named as smart fluid, which contains micron or nano sized magnetizable particles suspended in a viscous fluid. The fluid becomes a visco-elastic solid like material upon the application of a magnetic field and comes back to the normal stage on the removal of magnetism. The process of changing the properties of the fluid is instantaneous. The composition of these particles usually lies between 20 and 40 percent of fluid volume in an appropriate carrier liquid and the surfactants enhance the suspension of the particles.

Many research works had been carried out on the size of iron particles, which influences the performance of the damper. Particles with different size distributions could lead to differences in the visco-elastic behavior under the influence of a magnetic field [1]. Also, the larger particles used in the MRF could give higher yield strength compared to that of small particles and the particle size ratio in bi-dispersed suspensions can influence the shear stress. The reduction in the size of the particles is possible through a ball mill and uniform shape of particles of nanosize is possible by chemical synthesis [2–5]. Magnetic particles of nanowire could exhibit a better MR effect than traditional magnetic particles [6]. Applications of the MRF damper include automotive suspensions, passenger seat, pneumatic control, structural design, stroke rehabilitation systems, and human prosthetics [7–10]. [11] presents the synthesis of Fe_20_3 and its magneto viscous effects. The synthesis of Fe_20_3 and the measurement of viscosity of magneto rheological fluid are explained in [12]. This work studies the influence of the size of iron oxide particles with the help of synthesized and commercially available iron oxide particles and the novelty is to study the magnetic field strength on damping characteristics based on the response of the single degree of freedom (SDOF) quarter car model excited at different frequencies.

2. Experimental details

Researchers had used different configurations of MRF damper coils to study the performance of the damper. In this work MRF damper consists of a current carrying coil wound around the piston head in two stages, to have three annular orifices along the piston head. Two layers of sleeves, a metal and nylon, prevent the flux lines contact the body of the damper, as shown in Fig.1a. Each section has 216 numbers of turns of the coil of standard wire gauge SWG 19 as shown in Figs. 1, b, c and Fig. 2.

a b c

Fig. 1 MRF damper (a) cylinder with sleeve (b) piston head withwindings (c) assembled view

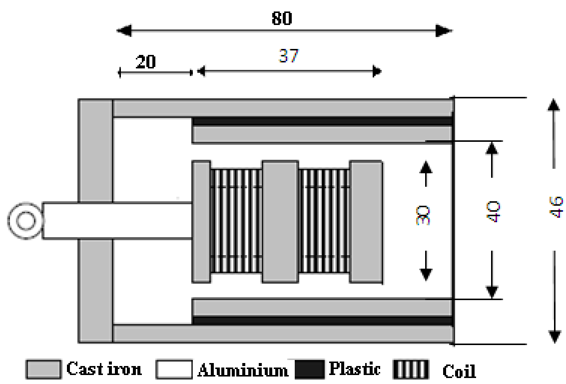

Fig. 2 Schematic representation of MRF damper

The clearance between the cylinder wall and the piston is 5 mm to permit the restricted fluid flow from the bottom side of the cylinder to the top side. The magnetic field strength on the surface of the electromagnet of the MRF was measured with the help of a Gaussmeter for different coil currents, and the variation of the magnetic field strength was found to be linear with coil current.

2.1. MRF oil preparation

Silicone oil of 200 ml having a viscosity of 1000 centistokes, white grease (Molykote) and iron oxide powders were used in the preparation of the MRF. Five grams (or 5.26 ml) of white grease was added to 55 g (60.7 ml) of silicone oil. The composition was stirred at a speed of 400 r.p.m at room temperature, for approximately four hours. Iron oxide powder (150 g or 49.6 ml), constitute 39 weight % of 200 ml was added to the above mixture and mechanically stirred for four hours. Synthesis of Fe_2O_3 was done by co-precipitation reaction reported in [11]. The characterization of iron oxide particles was carried out by X- ray diffraction (XRD) Technique using Rigaku Multiflex Diffraction machine (100 Watts) and Scanning Electron Microscopy (SEM) analysis was carried out using field emission scanning electron microscope (FESEM). The average particle size was found in a particle analyzer (Make: Malvern) using water as the dispersant with a viscosity of 0.8872 centi poise. The refractive index of the iron oxide was 2.91 and its material absorption coefficient was 0.10. The viscosity of the ferro fluid has been crucial in rheological studies and it has already been explored that the small size of nano particle changes the magnetic behavior of the ferro fluid compared to the classic cases of micron-sized ones.

A modified capillary tube arrangement measures the viscosity of the MRF at different magnetic field strengths based on the reference fluid [12]. The viscosity was determined based on the time taken for a 10g fluid measured using an analytical weighing machine. The density of glycerol was found to be 1260 kg/m^3 based on weight and volume calculation. Similarly, the density of the MRF was found to be 1690 kg/m^3. The viscosity of glycerol was used as the reference fluid and its value was experimentally determined as 1.499 Ns/m^2, using a glass viscometer.

2.2. Single degree of freedom (SDOF) quarter car model set up

A reduced scale model of a quarter car of 15 kg sprung mass system and its natural frequency is 2 Hz shown in Fig. 3 was taken for experimental work and the schematic diagram is shown in Fig. 4. Stiffness of the spring = 2380 N/m, the wire diameter of the spring = 2.5 mm, the coil diameter = 32 mm and number of turns of spring = 11.

A 50 kg capacity, vibration exciter of electro dynamic type and air cooled, excites the base of the quarter car model for the frequency range of 2 Hz to 20 Hz and in the interval of 2 Hz. The maximum peak to peak amplitude of vibration of the exciter was 12 mm. Maximum possible acceleration of the system was 80 g without any load. Two accelerometers of sensitivity 60 mV/g (Make: PCB piezotronics IEPE type) acquires base excitation and the topplate response. The data acquired with the help of accelerometers through data acquisition (DAQ) card were analyzed in the Lab View software 6.1 versions. The vertical displacement of the plates was obtained from acceleration data.

Fig. 3 Single degree of freedom experimental system setup

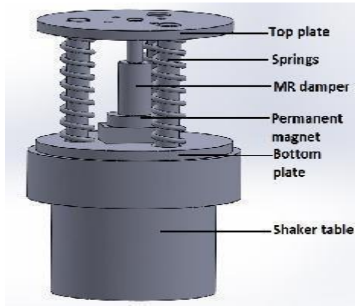

Fig. 4 Schematic diagram of single degree of freedom setup

The root mean square (r.m.s) value of the displacement was obtained from the data acquired by the accelerometer for 10seconds. The damping coefficient and damping ratio of the MRF damper for different magnetic field strength were obtained from the displacement of the top plate vs frequency plot using the half power method [13].

3. Results and discussion

This work focuses the characterization of the iron particles, influence of size of iron particles on the displacement, transmissibility ratio of the top plate of the SDOF for different frequency of base excitation.

3.1. Characterization of iron oxide particles

X-ray diffraction (XRD) was used to ascertain the phase of the synthesized and commercial powders. The peaks of XRD of synthesized powder and commercial powder were compared with the standard Fe_2O_3 as shown in Figs. 5 and 6.

The shape of the commercial powder was spherical and of synthesized powder was ultrafine size with a higher aspect ratio than for commercial powders. No sharp edges in commercially available powder were observed and the size distribution of the synthesized powder was homogeneous in nature Figs. 7 and 8. The average size of commercial powder was 1000 nanometers and of synthesized powder was 163 nanometers as shown in Figs. 9 and 10.

The magnetic field strength of the MRF damper for different coil current and viscosity of nano size iron oxide particles in the fluid hereafter call as nMRF and micron size iron oxide particles hereafter called as mMRF were presented in Table 1. The variation in the field strength was linear up to 0.1 A

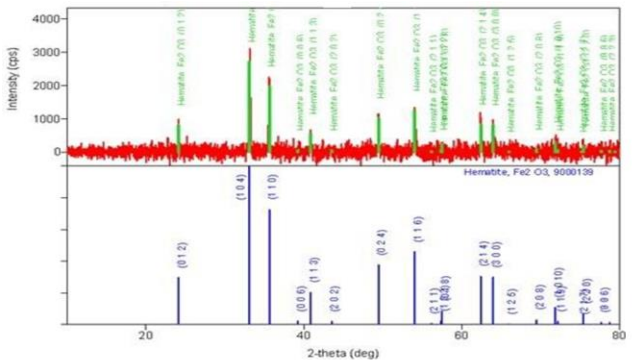

Fig. 5 X Ray diffraction pattern of commercial iron powder with standard iron oxide pattern

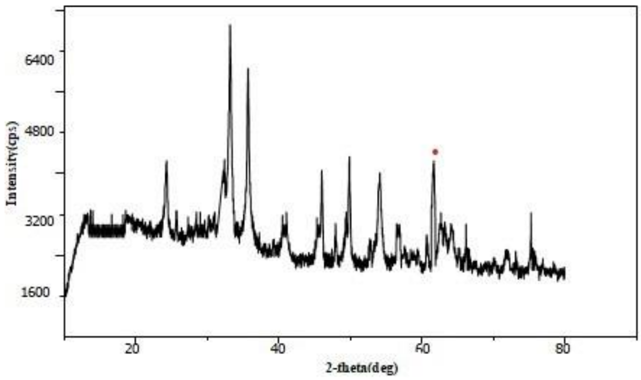

Fig. 6 X Ray diffraction pattern of synthesized iron oxide powder with standard iron oxide pattern

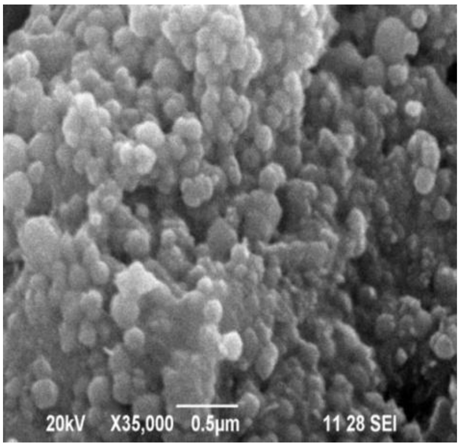

Fig. 7 SEM image of commercial powder

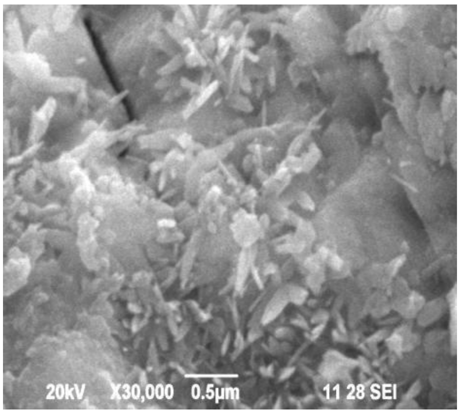

Fig. 8 SEM image of synthesized iron oxide powder

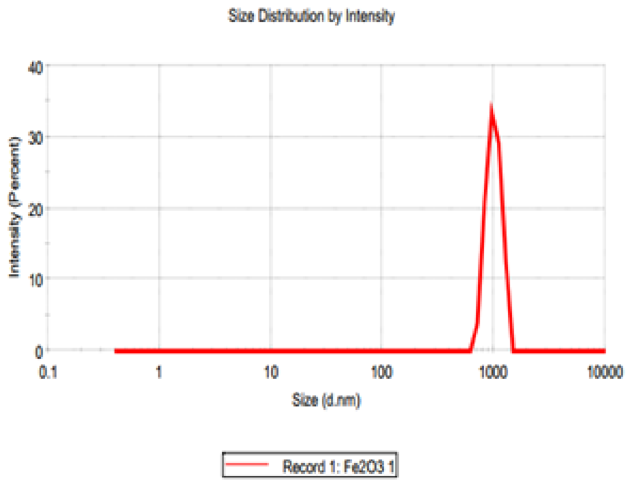

Fig. 9 Average particle size of commercial iron oxide powder

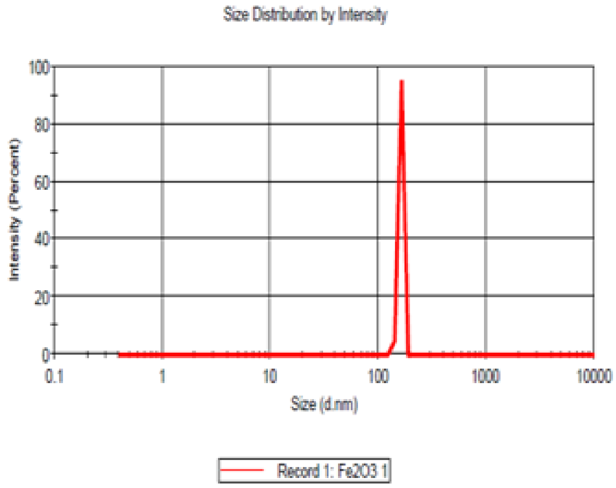

Fig. 10 Average particle size of synthesized iron oxide powder

Table 1

Influence of field strength on viscosity

Current, A	Hall's Probe, Gauss	Time taken for nMRF, s	Time taken for mMRF, s	Viscosity of nMRF, Ns/m^2	Viscosity of mMRF, Ns/m^2
0.00	0.0	124.20	132	14.91	15.84
0.02	4.0	127.27	138	15.28	16.50
0.05	6.0	131.06	145	15.74	17.40
0.08	9.6	137.21	151	16.47	18.12
0.10	11.4	189.77	189	22.79	22.68
0.15	12.3	263.13	210	31.60	25.21

3.2. Influence of magnetic field strength on the viscosity of the MRF

Thereafter, the variation was minimal. The reason would be the variation in the field strength occurred up to the maximum current carrying capacity, i.e. the saturation point of the coil after that the variation was less.The difference in viscosity between the nMRF and themMRF in non-energized condition can be attributed to the influence of morphology on iron oxide powder. The viscosity of the nMRF and the mMRF increases steadily with the current up to 0.08 A and increased abruptly thereafter. The reason could be a greater attraction of the iron oxide particles towards the coil of the damper and the forces between aligned iron oxide powders.The fluid behaved as a viscous liquid up to 0.08 A and undergoing transition to semi solid with nonlinear behaviour thereafter. The viscosity of the mMRF was found to be more than that of the nMRF up to 0.08 A and of higher coil current its value was lower than the nMRF. This might be due to the size and the shape dependency and the stability of the aligned columnar structure of iron oxide powders in oil in the presence of the magnetic field. Also, for the same weight fraction of iron oxide powder in oil, the number of particles and probability of alignment of powders would be larger in the case of the nMRF than the mMRF

3.3 Effect of size of iron oxide particle on acceleration of the SDOF quarter car model

The influence of the size of iron oxide power on vibration isolation of the SDOF was analyzed from accelerometer data of top and base plates of the SDOF for 0.02, 0.04, 0.06, 0.08 and 0.1 A coil current and frequencies of 2 Hz to 20 Hzin the interval of 2 Hz It was observed from the experimental results that the performance of the mMRF was better at the nMRF particles. The maximum reduction in acceleration of the nMRF was observed in 0.08 A coil current at 8 Hz. In the frequency range of 8 Hz to 20 Hz, the reduction was found to be good in the nMRF compared to the mMRF. The effect of size of the iron oxide powder was found to be less significant at lower frequencies. A significant improvement in the reduction of RMS acceleration of the top plate was found in the nMRF. It clearly showed an improvement in the passenger comfort due to the influence of size of iron oxide particles. The minimum acceleration of 74 mm/s^2 was obtained at 18 Hz for a coil current of 0.06 A in the nMRF and 67 mm/s^2 wasfound at 20 Hz for a coil current of 0.06A in the mMRF system as shown in Figs. 11 and 12. The flow behavior of fluid containing iron oxide to the tuned mass damper system. On energization, MRF flow behavior would be dominated by the columnar structure of iron particles and their response to vibration induced forces. Either due to the strong columnar structure or choking of particles at the orifices of the damper, the MRF acted as a solid/semi solid component adding significant spring mass or friction forces to the SDOF system. This could be the reason for the observed two peaks in the SDOF, against expected single peak response. Such two peaks were reported for tuned mass damper system [14]. The partial mass of the damper which gets added up to sprung mass at certain frequencies and amperage of the MRF might behave similar frequency of the system.

3.4. Influence of size of iron oxide particle on displacement of the SDOF quarter car model

The vertical displacement of the top and the bottom plates of the SDOF provide type deflection based on which the performance of vehicles was analysed. The damping coefficient of the nMRF and the mMRF were obtained from the peak values of frequency vs. displacement plot using the half power method. The RMS displacements of the top plate for different coil current in both nMRF and mMRF damper are in R.M.S. Displacement of the top plate of the SDOF for different coil current using nMRF and mMRF damper.

The influence of iron oxide powder size was implicit as the mMRF showed smaller vibration reduction of the same magnetic field and the magnetic property of the powder. This may be attributed to the size and the shape of powders which played a role in the stability of aligned powders i.e. powders formed a stable chain structure in the mMRF compared to that of the nMRF. The maximum variation in the displacement of the top plate was 117 μm occurred at 4Hz for the coil current of 0.04 A in the nMRF.

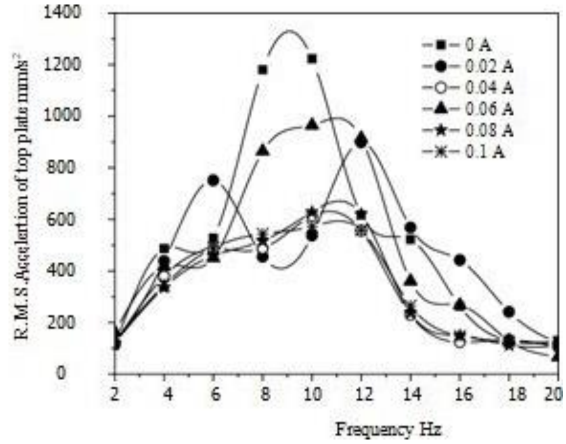

Fig. 11 R.M.S Acceleration of top plate for different coil current and frequency of SDOF quarter car model based on nMR

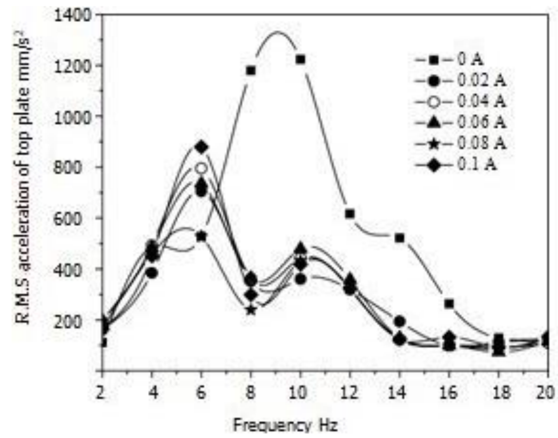

Fig. 12 R.M.S Acceleration of top plate for different coil current and frequency of SDOF quarter car model based on mMRF damper

The performance of the nMRF was better in a wide range of frequencies and in the case of the mMRF the performance was poorer at higher frequency. As the coil current increases the liquid becomes solid which results more vibration is transmitted to the top plate. The damping coefficient and damping ratio of the nMRF and the mMRF increase linearly as the coil current was increased, except for 0.04A energization. The variation of the damping coefficient was non-linear in both the nMRF and the mMRF as shown in Figs. 13 and 14. At all ranges of current supplies of the MRF, the nMRF had a higher damping coefficient and damping ratio except for 0.02 A and 0.1 A. For 0.04 A energization of nMRF, the columnar structure response to the frequency, had yielded a higher damping coefficient. Hence, the nMRF energized with 0.04A would be preferred. For energization of the nMRF with 0.1A, the damping ratio was 0.99, the highest among the range of current studied. This may be due to response of the stable columnar structure of particles to the frequency of vibration.

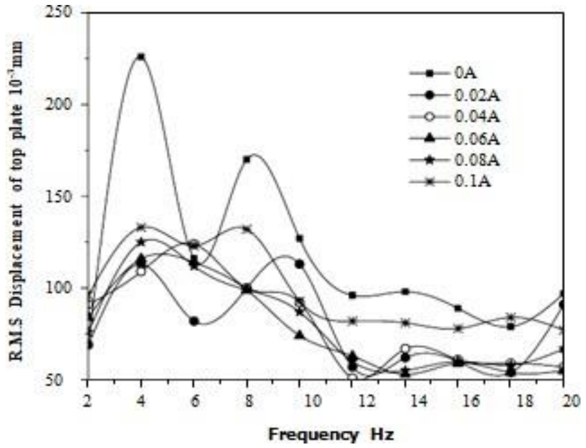

Fig. 13 R.M.S Displacement of the top plate for different coil current and the frequency of the SDOF quarter car model based on nMRF

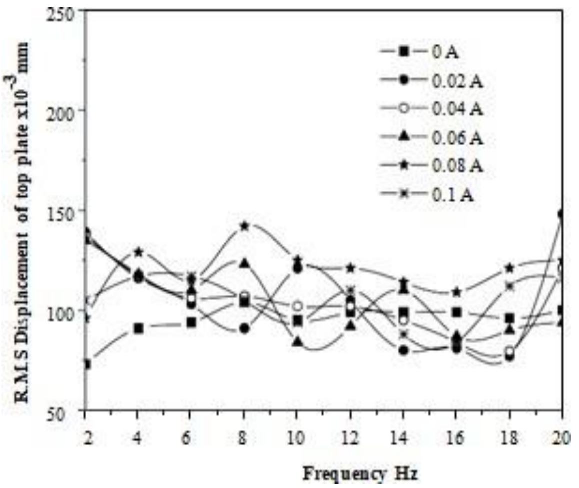

Fig. 14 R.M.S Displacement of the top plate for different coil current and the frequency of the SDOF quarter car model based on mMRF damper

Comparing the response of the top plate with different base excitations was found to be difficult. The variation in the reduction of vertical displacement of the nMRF and the mMRF at each frequency was found to be different. In the case of the mMRF system operated at 0.06 A, the percentage reduction was found to be negative at 12 Hz and 14 Hz. This might be due to MRF acting as a semi solid rigid member with some stiffness whereby the vibration amplitude was amplified rather than vibrationsuppression.

The effect of size of particles, can be inferred by damping coefficient and damping ratio of the nMRF and the mMRF for particular current value. The highest values of damping coefficient and damping ratio of the mMRF were observed at 0.1 A. which could be the reason of columnar structure. The peaks formed by particle of micron size in response to the magnetic field and the frequency of vibration was uniform in nature. This shows the influence of size of iron oxide powder on improving theperformance of the system. The value of the transmissibility ratio of the nMRF of different frequencies of base excitationfor the coil current of 0.1 A was than more unity. The viscosity of the fluid increases at higher coil current and the transmissibility of vibration is more. The maximum variation in the transmissibility ratio between the nMRF andthe mMRF was 1.29 at 0.02 A coil current for the frequency ratio of 4.

Table 2

Damping coefficient and damping ratio of nMRF and mMRF

Coil current, Amp	nMRF		mMRF	
	Damping Coefficient, Ns/m	Damping ratio ξ	Damping Coefficient, Ns/m	Damping ratio ξ^*
0.02	364	0.49	500	0.68
0.04	955	0.87	516	071
0.06	682	0.93	546	0.74
0.08	682	0.93	569	0.78
0.1	728	0.99	1001	1.37

The system based on the nMRF energized at 0.04A showed the maximum percentage reduction of vibration of the top plate of the SDOF quarter car model test. Notably the range of variation in amplitudes of the top plate with the nMRF system was less than that of the mMRF at all frequencies shown in Fig. 15. Further, the powerconsumption for the best vibration reduction at a specific frequency was found to be smaller for the nMRF than mMRF. The transmissibility ratio of the nMRF at different base excitation frequencies was found to be less than unity and was more than unity in the mMRF damper.

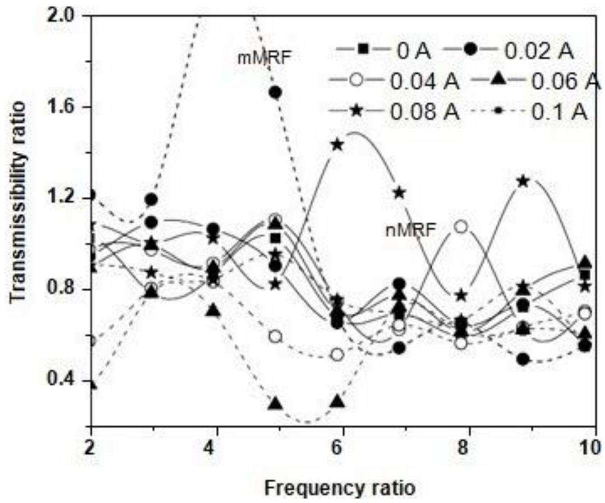

Fig. 15 Frequency ratio and Transmissibility ratio of SDOF

4. Conclusions

The performance of the SDOF quarter model using the MRF damper has been studied experimentally and the results show that the nano iron oxide powder based MRF has better damping characteristics than micron sized iron oxide powder containing the MRF in terms of the higher percentage of reduction in the vibration amplitude of the top plate, less variation over the frequency range of 2-20 Hz and low magnetic field strength. Both sizes as well as shape of iron oxide powder seem to play a role in the formation of the columnar structure and ability to restructure upon collapse due to vibration in the presence of the magnetic field. The synthesized iron oxide powder was found to be a magnetite phase by XRD analysis and the size of powder was 160 nm from particle analyzer. The morphology of commercial powder was spherical whereas synthesized nanosized powder was needle shaped. The commercial iron oxide powder was 1000 nm in size. The influence of size ofthe iron oxide particles and the magnetic field on damping an MRF damper was profound on the SDOF quarter car model. The viscosity of the nMRF was higher than the mMRF and it influenced on the resonance frequency. The significant improvement in the performance of vibration isolation was due to the reduced size of iron oxide particles. With respect to tyre deflection and suspension travel, both the nMRF and the mMRF exhibited similar levels of performance. All these results may be considered as a database for building feedback control of an active MRF suspension system.

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References

1. **Chiriac, H.; Stoian, G.** 2010. Influence of particle size distributions on magnetorheological fluid performances, Journal of Physics: Conference Series 200: 072095. https://doi.org/10.1088/1742-6596/200/7/072095.
2. **Fouda, M. F. R.; El-Kholy, M. B.; Moustafa, S. A.; Hussien, A. I.; Wahba, M. A.; El-Shahat, M. F.** 2012. Synthesis and characterization of nanosized-Fe_2O_3 pigments, International Journal of Inorganic Chemistry 989281: 9. https://doi.org/10.1155/2012/989281.
3. **Park, B. J.; Song, K. H.; Choi, H. J.** 2009**.** Magnetic carbonyl iron nanoparticle based magnetorheological suspension and its characteristics, Materials Letters 63: 1350-1352.
4. **Susan-Resiga, D.; Bica, D.; Vekas, L.** 2010. Flow behaviour of extremely bidisperse magnetizable fluids, Journal of Magnetismand Magnetic Materials 322: 3166- 3172.
5. **Xinghong Wang; Li Zhang; Yonghong Ni; Jianming Hong.; Xiaofeng Cao.** 2009. Fast preparation, characterization, and property study of α- Fe2O3 nanoparticles via a simple solution-combusting method, Journal of Physical Chemistry C113: 7003- 7008. https://doi.org/10.1016/j.jmmm.2010.05.055.
6. **Roszkowski, A.; Bogdan, M.; Skoczynski, M.; Marek, B.** 2008. Testing viscosity of MR fluid in magneticfield, measurement science review 8(3): 58-60. https://doi.org/10.2478/v10048-008-0015-x.
7. **Bajaj, H. M.; Birdi, G. S.; Ugale, B.A.** 2014**.** Application of magneto rheological (Mr) fluid damper and its social impact, International Journal of Mechanical and Production Engineering 2: 41-45.
8. **Nguyen, P. B.; Do, X. P.; Jeon, J.; Choi, S. B.; Liu, Y.D.; Choi, H. J.;** 2014. Brake performance of core–shell structured carbonyl iron/silica based magnetorheological suspension, Journal of Magnetism and Magnetic Materials 367: 69-74 https://doi.org/10.1016/j.jmmm.2014.04.061.
9. **Rajendran, A.; Hollitt, C.; Browne, W, N.** 2011. Investigating the use of magneto-rheological fluid in an active compliant actuator for a stroke rehabilitation system, Proceedings of the Australasian Conference on Robotics and Automation, pp. 1(8).
10. **Zhu, S.; Shen, W.; Xu, Y.** 2012. Linear electromagnetic devices for vibration damping and energy harvesting: modeling and testing, Engineering Structures 34: 198-212. https://doi.org/10.1016/j.engstruct.2011.09.024.
11. **Hezaveh, H.; Fazlali, A.; Noshadi, I.** 2012. Synthesis, rheological properties and magneto viscous effect of Fe2O3/paraffin ferrofluids, Journal of the Taiwan Institute of Chemical Engineers 43: 159-164. https://doi.org/10.1016/j.jtice.2011.07.003.
12. **Tamilmagan, M.; Easu, D.; Baskarlal, V.; Andal, V.** 2015. Synthesis, characterisation, design and study of magnetorheological property of nano Fe2O3, National conference on Nanomaterials for Environmental 8: 65-69.
13. **Den Hartog, J, P.** 1985. Mechanical vibrations (Courier Corporation).
14. **Weber, F**. 2014. Semi-active vibration absorber based on real-time controlled MR damper, Mechanical Systems and Signal Processing 46: 272-288. https://doi.org/10.1016/j.ymssp.2014.01.017.

E. Dakshnamoorthy, S. Arjunan, A. Radhakrishnan, A. Gopal

STUDY ON THE INFLUENCE OF SYNTHESIZED NANO FERRITE POWDER AND MICRON FERRITE POWDER ON DAMPING OF SINGLE DEGREE OF FREEDOM SYSTEM

S u m m a r y

Magneto Rheological Fluid (MRF) damper has beenopted as a promising semi active element of advanced suspension system. This work focuses on the damping nature of magnetorheological fluid under the influence of amagnetic field strength, size and shape of the of the iron oxide particles. A reduced scale single degree of freedom quarter car model with two stage magnetorheological damper, viscosity measurement setup, synthesized and commercially available Fe_2O_3 powders are used for the experimental study. An air cooled electro-dynamic shaker, Data acquisition system, accelerometers and the Lab view software acquires and analyzes the response of the quarter car model. X-ray Diffraction and Scanning electron microscopy characterize the morphology of iron oxide particles. The vertical acceleration, the displacement, the transmissibility ratio and the damping characteristics are analyzed based on the response of the top plate at different frequencies of base excitation. The results show that the magnetorheological fluid with nano iron oxide powder has better damping characteristics than that of micron sized iron oxide powder.

Keywords: quarter car model, nano iron oxide powder, MRF damper, transmissibility ratio.

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