DEVELOPMENT AND TESTING OF MRE BUSHING FOR ROAD VEHICLE SUSPENSION SYSTEM

S. R. Kumbhar[1], Subhasis Maji[2], Bimlesh Kumar[3]

[1] Research Scholar, School of Engg. & Technology, IGNOU, New Delhi, India
kumbharsr@rediffmail.com
[2] Director, School of Engg. & Technology, IGNOU, New Delhi, India
subhasis@ignou.ac.in
3 Principal, J.T. Mahajan College of Engg., Faizpur, Maharashtra, India
bimlesh2000@rediffmail.com

ABSTRACT

The suspension bushings are important design element that plays a significant role in determining the ride comfort and handling of the vehicle. In order to provide maximum ride comfort, bushing should be as soft as possible, while in order to provide optimal handling, bushings should be as hard as possible. To compensate this design requirement, variable stiffness suspension bushing should be used. For this, smart material like magnetorheological elastomer (MRE), whose mechanical properties changes with applied magnetic field, is required. This paper represents performance characteristics of rubber bushing in terms of its transmissibility related to isolation. Testing of MRE bushing is carried out with the help of quarter car test rig, which closely resembles to the quarter part of vehicle. The Macpherson suspension is selected for quarter car test rig because of its simplicity, compact design and it's widely applications. Lower control arm bushes were fabricated by MRE, consisting of silicone elastomer with iron powder of varying sizes. MRE bushing was cured in the absence of magnetic field hence can be termed as isotropic MRE bushing. The results show appreciable effects of MRE bushings.

KEYWORDS

Bushings, magnetorheological elastomer, transmissibility and quarter car test rig.

1. INTRODUCTION

The main function of suspension system is to provide good road holding while driving, cornering and braking and at the same time it maintains proper steering geometry. The suspension bushings play a significant role in determining the ride comfort and handling of the vehicle. Stiff suspension bushings will yield excellent handling but poor in ride comfort, whereas softer suspension bushings significantly improve ride comfort at the expense of vehicle handling. Even if vehicle is outfitted with active or semi-active suspension system, the bushings have same problem. To compensate this problem variable stiffness bushings should be used. For achieving these trade-off requirements, smart materials can be used to prepare bushings. Smart materials are materials with properties that can be significantly altered in a controlled fashion by external stimuli, such as stress, temperature, electric or magnetic fields [1-2]. An elastomer comprising a matrix interspersed with micron sized ferromagnetic particles is known as a Magnetorheological Elastomer (MRE) [3]. Due to controllable stiffness, MRE will offer innovative solution for this problem. In this paper, quarter car test rig is used to study the behaviour of MRE bushing at different load conditions. Macpherson suspension system is selected for quarter car test rig because of its simplicity in structure and widely used in automotive vehicles. The rubber bushings used in the Macpherson suspension are replaced with MRE bushing.

2. EXPERIMENTATION

2.1. MRE Bushing Preparation:

T. Shiga, in 1955 put forward the concept of Magnetorheological Elastomer. Before this time, Magnetorheological phenomenon was introduced by Thomas Rainbow. Magnetorheological Elastomer (MRE) is a branch of MR materials, whose rheological properties can be controlled rapidly and reversibly by the application of an external magnetic field. MRE typically consist of micron-sized magnetic particles suspended in a non-magnetic matrix. Particles inside the elastomer or gel can be homogeneously distributed or they can be grouped to form chain-like columnar structures [4-8]. To produce an aligned structure, magnetic field is applied to the polymer composite during cross linking so that columnar particle structures form and become locked in their place upon the final cure [1, 9, 12-13].

The magnetic interactions between particles in these composites depend on the magnetization orientation of each particle and on their spatial relationship, coupling the magnetic and strain fields in these materials and giving rise to a number of interesting magneto-mechanical phenomena. MREs have a controllable, field-dependent modulus which means the strength of MREs is typically characterized by their field dependent modulus [8-9].

Full-proof process for MRE preparation has not been provided in previous literatures. For preparation of MRE, different types of rubbers were available in market. While selecting a particular type of rubber, its properties and availability were considered. In this work, Sylgard's184 silicone elastomer was selected due to its inherent advantages like - it cures at constant rate, regardless of sectional thickness degree of confinement, works in wide temperature range that is from -45ºC to 200ºC, post curing is not require at any condition, available easily, shrinkage is minimum at the timing of curing, no exothermal reaction taking place during curing, clean curing process without formation of any byproducts, and having a good dielectic properties [10-11)]. The Sylgard's184 was available in two parts namely part A, and part B. Part A is base while part B is curing agent. It was recommended to mix A and B in proportion of 10:1.

Figure 1. Fabricated MRE Bushings

The upper strut and control arm bushing of Macpherson suspension were prepared with MRE, as per the dimensions of rubber bushing earlier available. Four bushings of each type were fabricated with varying the proportion of 20% and 30% by volume of 5μ and 10μ iron particle size (Fig.1).

2.2. MRE Bushing Testing & Results:

Transmissibility is a measurement used in the classification of materials for vibration management characteristics. It is a ratio of the vibrational force being measured in a system to the vibrational force entering a system. It can be determined by taking excitations in acceleration, displacement or velocity terms. Figure 2 shows a typical transmissibility curve. It shows that, as frequency increases, the amount of energy transmitted from vibrations is reduced (i.e. isolation performance increases). The hatched line indicates the region of amplification and isolation.

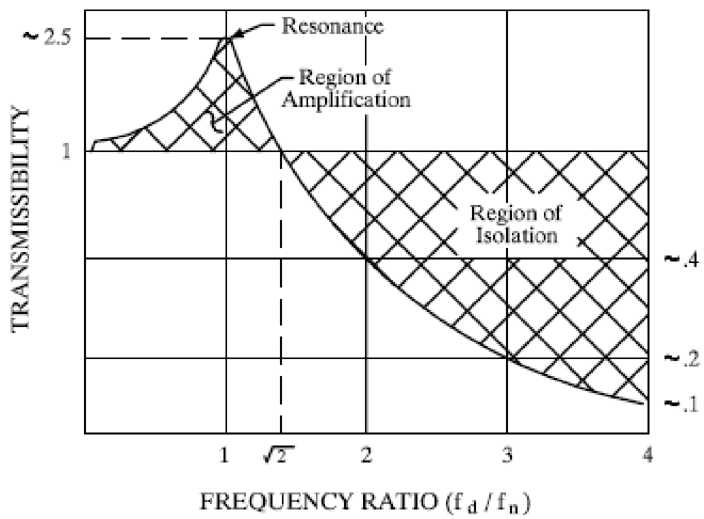

Figure 2. Typical Transmissibility Curve

The formula to find transmissibility is -

$$Transmissibility = \frac{A_o}{A_i} = \sqrt{\frac{1 + \left(2\xi \frac{f_d}{f_n}\right)^2}{\left[1 - \left(\frac{f_d}{f_n}\right)^2\right]^2 + \left[2\xi \frac{f_d}{f_n}\right]^2}} \qquad \text{--------------------------------- (1)}$$

Where,

A_0 = Amplitude of the Vibrational Response (Output)

A_i = Amplitude of the Vibrational Input

ξ = Damping Ratio; f_d = Driving Frequency; f_n = Natural Frequency

Instead of using equation (1), which includes the parameter damping ratio, in this experimental study we have taken acceleration measurements to determine the transmissibility.

The Macpherson suspension of Maruti 800 has been selected for testing of prepared MRE bushes (Fig.3). The arrangement is made in the test rig for applying magnetic field at the upper strut and at the control arm of suspension system. Various instruments like accelerometers, FFT analyzer, Data acquisition and analysis software were used for getting required results. The set up also includes the excitations received from electric motor, base plate and accelerometers A_i and A_0.

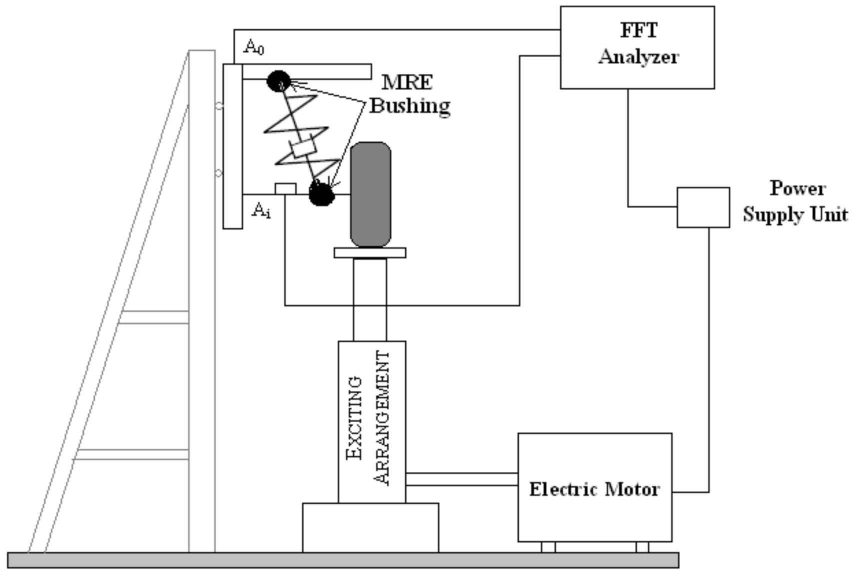

Figure 3. Quarter Car Test Setup

In experimental testing, the readings for input acceleration and output accelerations (As shown in fig.3) have been recorded. The reading were taken for rubber bushing and then by using MRE bushing at various loading conditions and at varying applied magnetic fields. The frequency range was selected as in between 50 Hz to 70 Hz. The acceleration values taken by upper accelerometer is divided by acceleration values taken by lower accelerometer to calculate transmissibility of each frequency sweep. From the calculations it is observed that the resonant frequency increased with increase in applied magnetic field. The sample table of data for 5μ - 20% MRE bushing at 600 N load and 0 T applied magnetic field is shown in following Table 1.

Table 1. Lower (A_i) and Upper Acceleration (A_0) values of 5μ - 20% MRE Bushing at 600 N and 0 T

Sr. No.	1	2	3	4	5
A_o	0.271	0.466	0.774	0.591	0.342
A_i	0.077	0.087	0.126	0.119	0.135
f_0	54	56	58	60	63

From above transmissibility versus frequency plots the change in resonant frequency at highest transmissibility for each condition are tabulated in Table 2.

Table 2. Transmissibility MRE bushings and Rubber bushing

Sr. No.	Bushing	Load (N)	At 0 T Magnetic field		At 0.192 T Magnetic field		$\Delta f/f_o$ (%)
			Resonance Frequency f_0 (Hz)	Transmissibility (A_o/A_i)	Resonance Frequency f_1 (Hz)	Transmissibility (A_o/A_i)	
1	5µ - 30% MRE	200	58	2.9	62.5	8.4	20.1
		400	53.5	3.82	66	7.62	23
		600	52	5.09	63	8.4	8
2	5µ - 30% MRE	200	65	3.42	78	3.54	18
		400	65	4.37	73	3.88	12.3
		600	65	5.29	73	11.36	12.3
3	10µ- 20% MRE	200	63.5	5.03	74	5.45	9
		400	63.5	4.38	73	4.83	4.1
		600	65	5.29	73.5	6.45	2
4	10µ- 30% MRE	200	66.5	6.65	72.5	7.57	16.5
		400	73	10.82	76	8.13	12.3
		600	73	10.82	75.5	4.76	13
5	Rubber Bushing	200	45.5	2.8	-	-	-
		400	46.5	3.4	-	-	-
		600	60.5	3.9	-	-	-

Table 2 shows that transmissibility increases as applied magnetic field increases. It is also seen from graphs of transmissibility v/s frequency that the value of transmissibility is greater for 0.96 T magnetic fields than at 0T at all loads. For rubber bushing, transmissibility increases with increase in load conditions but it remains lower as compared to MRE bushings.

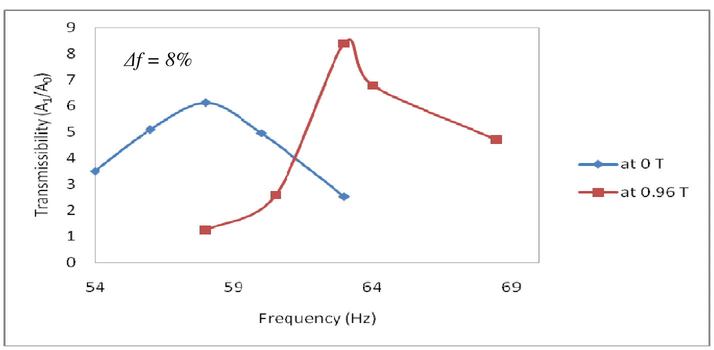

Figure 4. 5µ - 20% MRE Bushing (600 N Load)

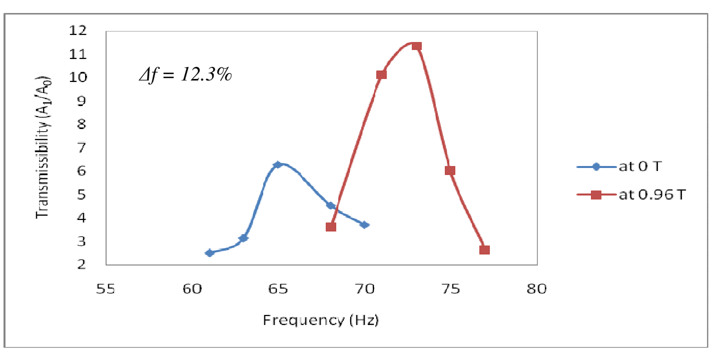

Figure 5. 5µ - 30% MRE Bushing (600 N Load)

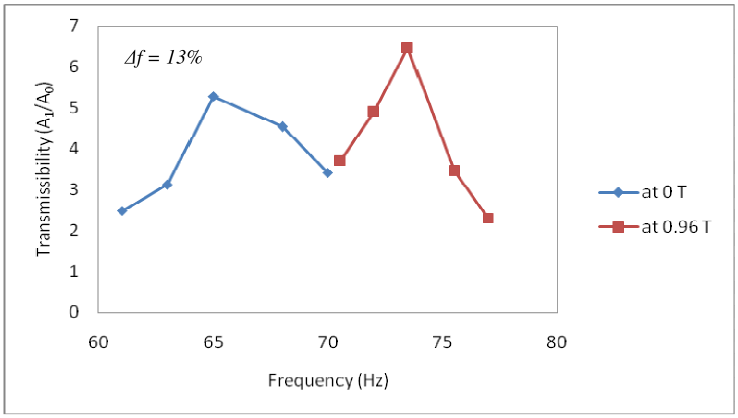

Figure 6. 10μ - 20% MRE Bushing (600 N Load)

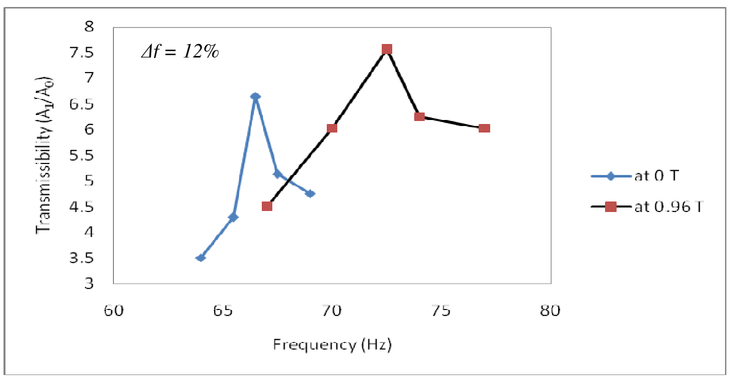

Figure 7. 10μ - 30% MRE Bushing (600 N Load)

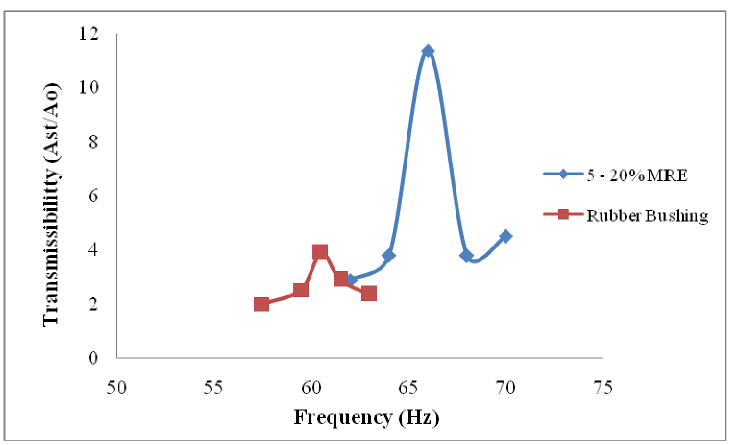

Figure 8. Rubber Bushing and 5μ - 20% MRE Bushing (0.768 T and 400 N Load)

3. RESULTS AND DISCUSSIONS

During testing frequency responses were taken for different load conditions, for different MRE bushing, with and without applying magnetic field. From the frequency curves, values of frequencies f_0 and f_1 and accelerations A_1 and A_2 were recorded. As we increase the % of iron particles, the transmissibility shows is better.

Table 2 shows that transmissibility increases as applied magnetic field increases. It is also seen from graphs of transmissibility v/s frequency that the value of transmissibility is greater for 0.768T magnetic flux density than at 0T magnetic flux density at all loads. For rubber bushing, transmissibility is increases with increase in load conditions but it remains lower as compared to MRE bushings. The transmissibility ratio is greater for MRE with 20% of 5μ iron particle size as compared to other MRE and rubber bushings.

Figure 4 shows the transmissibility curve for 5μ - 20% MRE Bushing with 600 N Load. This curve shows the shifting of curve to right with Δf = 8%. But after changing the percentage of iron practical's from 20% to 30%, fig. 5 shows the shift of Δf = 12%. Also the transmissibility curve shows more values than 20% iron particles.

In the figure 6 and 7, the transmissibility curve has been shown for 10μ, 20% and 10μ, 30% MRE Bushing. 10μ, 20% MRE bushing shows Δf = 13% while 10μ, 30% MRE bushing shows Δf = 12%. This indicates that, by increasing the percentage of iron particles at increased micron size, we could not get the increase in transmissibility curve shift, but we could get the more transmissibility.

Figure 8 compares the transmissibility for rubber bushing and MRE bushing. This shows that the transmissibility of MRE bushing is higher than rubber bushing. Hence finally we can conclude that the MRE bushing gives better results than rubber bushing. This property can be utilized for reducing structure-borne noise and vibrations in automobile.

4. CONCLUSIONS

Suspension bushings are important design elements that play a significant role in determining the ride comfort and handling of the vehicle. In order to provide maximum ride comfort, bushing should be as soft as possible, while in order to provide optimal handling, bushings should be as hard as possible. To compensate this design requirement variable stiffness suspension bushing should be used. MRE bushings for upper strut bushing and lower control arm bushing were fabricated using 20% and 30% by volume of 5μ and 10 μ iron particle size and tested with the help of quarter car test rig. The developed MRE bushing shows better transmissibility over rubber bushing which can be correlated to isolation requirements.

In nutshell, MRE bushing could become one of the important options for reducing structure-borne noise and vibrations (isolation) in automobiles.

ACKNOWLEDGMENT

Authors are very grateful to Dr. S. G. Joshi, Emeritus Professor, WCE, Sangli for their appropriate and constructive suggestions during preparation of this paper.

REFERENCES

[1] http://www.ask.com
[2] http://metallurgyfordummies.com
[3] C. Ruddy, E. Ahearne, G. Byrne, 2008. A review of magnetorheological elastomers: properties and applications, Advanced Manufacturing Science (AMS) Research Centre, Mechanical Engineering, University College Dublin, Belfield, Dublin 4, Ireland, 1-4.
[4] Weihua Li and Xianzhou Zhang, 2008, Research and applications of MR elastomers, Recent Patents on Mechanical Engineering,1, 161-166.
[5] Danuta Miedzinska, Grzegorz Slawinski, 2010, Numerical simulation of the beam made of magnetorheological elastomer bending in the magnetic field, Journal of KONES Power train and Transport, Vol. 17, No. 1.
[6] Xianzhou Zhang, Weihua Li, X.L. Gong, 2008, An effective permeability model to predict field-dependent modulus of magnetorheological elastomers, Communications in Nonlinear Science and Numerical Simulation,13, 1910–1916.
[7] http://www.belgeler.com
[8] Koray Ozsoy, 2008, A mathematical model for magnetorheological materials and magnetorheological devices, M.Sc. Thesis, Suleyman Demirel University, 2008
[9] M. R. Jolly, J. D. Carlson, B. C. Munoz, T. A. Bullians, 1996, The magnetoviscoelastic response of elastomer composites consisting of ferrous particles embedded in polymer matrix, Journal of Intelligent Material Systems and Structures, Vol.7, 613- 622.
[10]Marke Kallio, 2005, The elastic and damping properties of magnetorheological elastomers, Master Thesis, Tampere University of Technology, VTT Publications.
[11] Michael H. Sjoerdsma, 2005, Controlling structure-borne noise in automobile using magnetorheological components, Master Thesis, Simon Fraser University.
[12] H. Bose, R. Roder, 2009, Magnetorheological elastomer with high variability of their mechanical properties, Journal of Physics, 11th Conference on Electrorheological Fluids and Magnetorheological Suspensions, IOP Publication, 1-7.
[13] Larry D. Ellie, John M. Ginder, William M. Stewart, Mark E. Nichols, 2002, European Patent. EP0784163, Ford Motor Co, GB.

Authors Short Biography

Prof. S. R. Kumbhar, has completed AMIE (Mech.) **&** M.E. (Mechanical Design Engineering). Since 1991 he has been with Automobile Engineering Department at Rajarambapu Institute of Technology, Rajaramnagar, Sakharale. Presently he is working as Assistant Professor in Automobile Engineering Department. He has published more than 29 papers at National & International Seminar / Journals etc and 03 books. His area of research includes automotive suspension, noise & vibration, I. C. engines

Prof. Dr. Subhasis Maji, Director, School of Engineering & Technology SOET), IGNOU, has completed B.E. (Mechanical), Ph.D.(IITD), PGDDE, MADE (Gold Medal), PGDHE, MBA, PGJMC, PGDRD (Gold Medal). He has published number of papers at National & International Journal / Seminars etc. His area of interest is Fluid Mechanics, Thermodynamics, Higher Education, Refrigeration and Air Conditioning, Numerical Analysis, Management (HRD). He had served different positions as academician and successfully completed different projects.

Prof. Dr. Bimlesh Kumar, Principal, JT Mahajan College of Engg. Faizpur, has completed B.E.(Auto.), Ph.D. (Mech.). He is member and reviewer of IJAV. He has published number of papers at National & International Journals / Seminar etc. He has guided / guiding number of research scholars in Solapur, Pune, Delhi, Chennai Universities. His area of interest includes Stress Analysis, Vibration, ER Fluid. He had served different positions as academician and successfully completed different projects.