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Vibrational Analysis of Magneto-Rheological Elastomer under Different Loading

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Abstract : This report presents the experimental and analytical modal analysis of a magneto-rheological elastomer. The effective material and geometrical properties are measured, and the dynamic behaviour is investigated through testing. Fabrication of isotropic and anisotropic magneto-rheological elastomers with different percentages of iron particles are carried out. Also two numbers of silicon elastomer in which one having steel net kept layer by layer in place of iron particles during pouring of liquid silicon elastomer in mould, other is simple silicon elastomer without iron particle or steel net are fabricated.The modal analysis of all samples are being analyzed using FFT analyser. And transmissibility and amplitudes of all samples are compared with respect to load. A comparative study has been made between different samples of MRE's using results and comparisons obtained using experimental method.
Keywords: Smart material, Magneto-rheological elastomer, Transmissibility, FEM, FFT Analyser

I. INTRODUCTION

Recently, a very attractive and effective semi-active absorbers featuring magneto-rheological (MR) materials such as MR fluids (MRFs) or MR elastomers (MRE's) have been proposed by many investigators. These absorbing devices based on MR technique have a number of attractive characteristics for use in vibration control, such as fast response characteristic to magnetic field, wide control bandwidth and compact size. MR materials include MRFs, MR foams and MREs, whose rheological properties can be controlled by the application of an external magnetic field. The most common MR material is MRFs, which is magnetically polarizable particles suspended in viscous fluids. Since their invention in 1948, MRF technique has made significant advancements. The MRFs have been proved to be commercially viable and well suited for many applications, such as the automotive suspension vibration control, the earthquake resistance, clutch.

Solid analogs of MRFs and MREs can avoid those disadvantages such as settling of particles normally associated with MRFs. MREs include a wide variety of composite materials, which typically consist of magnetically polarizable particles dispersed in a polymer medium. The mechanical properties of MREs such as the storage and loss modulus are altered reversibly by the application of an external magnetic field. Moreover, MREs do not need channels or seals to hold or prevent leakage, are more stable and avoid the particle sedimentation associated with MRFs. Therefore, MREs have many potential engineering applications for vibration control in damping and vibration isolation systems.

Base isolation systems are the most widely implemented technique world-widely for the seismic protection. When earthquake comes, the base isolation system will decouple external vibrations by isolating destructive frequency contents from transmitting into the main structure above thus maintain the integrity and safety of the structure and contents therein. A new smart material, Magnetorheological (MR) elastomer, promises a solution for overcoming these challenges by developing an adaptive base isolator. MR elastomer consists of natural or synthetic rubber matrix interspersed with micron sized (typically 3 to 5microns) ferromagnetic particles. Similar as MR fluids, MR elastomers possess magnetic field-sensitive shear modulus and damping which can be controlled by external magnetic field. Under magnetic field, the material switches from rubber-like property into solid material. After removing the magnetic field, it regains its original state as a rubber. Notably, this process is instant, reversible and repeatable. Due to these attractive features, MRE has received a great deal of attention to be used in the development of vibration isolators and vibration absorbers.

The structure of magnetorheological elastomer in Fig.1 shows that when a magnetic field is applied the ferromagnetic particles arrange into chains (particle clusters) parallel to the magnetic field lines. Chains may interconnect and branch off forming fibrils. In order to shear the magnetorheologicalelastomer under a magnetic field extra force must be exerted to break the cluster of chains/fibrils.

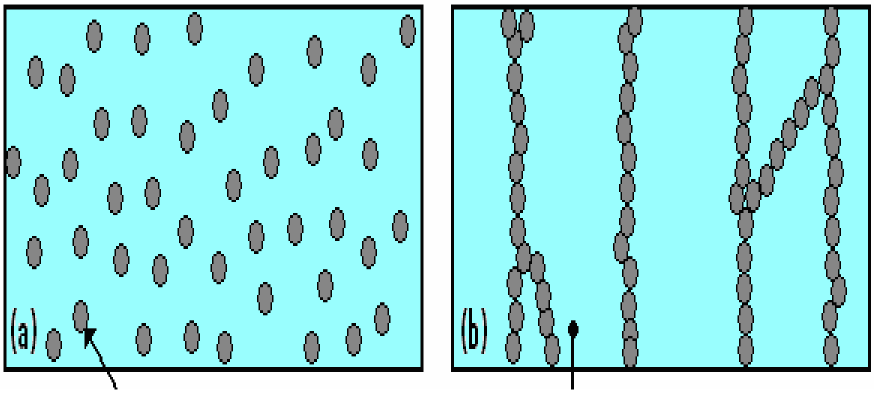

Figure 1 : Structure of Magnetorheological elastomer, Ferromagnetic particles in a elastomer (a) under no magnetic field, and (b) with magnetic field applied.

II. FABRICATION OF MAGNETO-RHEOLOGICAL ELASTOMERS

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 RTV Sylgard's184 silicone elastomer (made from Dow corning Ltd. Powai, Mumbai) 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. 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.

Table 1. Fabrication of magnetorheological elastomers

Sample	Sample Type	Content (by weight in gm.)					Total weight of sample	Total weight after curing
		Liquid Si Rubber	Curing agent	Si oil	Iron particle	Curing time in Hrs.		
1	Isotropic MRE	100	10	10	15	48	135	240
2	Anisotropic MRE							
3	Isotropic MRE	100	10	25	30	48	165	260
4	Anisotropic MRE							
5	Isotropic MRE	50	5	50	350	48	455	470
6	Anisotropic MRE							
7	Elastomer with steel net	50	5	10	steel net wt. = 20	48	85	120

The materials used for the MREs are: RTV liquid silicone rubber with its curing agent, silicone oil, and carbonyl iron particles, The diameters of the iron particles are between 3 μm and 5 μm. The mixture of RTV liquid silicone rubber (Part A) and its curing agent (Part B) with 10:1 proportion was mixed properly by electric stirrer also without waste of time second mixture of silicon oil (350 CTSK) and carbonyl iron particle of 3 to 10 micron size with given proportion was mixed by same process. These two mixture throughly mixed together by electric stirrer and then it was put into a vacuum case to remove the air bubbles inside it, and then the mixture was poured into a mold for curing under constant magnetic field. The curing time for MRE sample is 48 hours. By taking lots of efforts and observations under expert's guidance, four MRE moulds were fabricated. Fig. 2 shows the sample of Isotropic MRE, Fig. 3 shows the sample of Anisotropic MRE and Fig. 4 shows the sample of Elastomer with steel net.

Figure 2 : Sample of Isotropic MRE (Sample no.1,3,and 5)

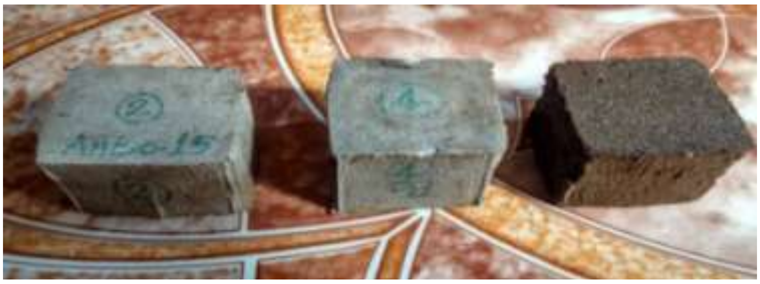

Figure 3 : Sample of Anisotropic MRE (Sample no.2,4,and 6)

Figure 4 : Sample of Elastomer with steel net (Sample no.7)

III. EXPERIMENTAL SYSTEM DEVELOPMENT

This section discusses the process of manufacturing as well as the components of the experimental systems; the type of signal employed, and test results.

Figure 5 : Experimental set up

The experimental set up consist of portable dead channel FFT, vibration table, laptop and two accelerometers (one placed near or on the vibration exciter and other on top on mass pan).The MR elastomer was used in this study has 50×50×40 (lbh) in dimension. Also it requires fixture for testing containing two steel plates for resting the sample in between them by nut and bolt. For this, the test set-up used was as shown in figure 3.1.Prior to the start of the experiment the whole set up is mounted on vibration table with connection of FFT and was ran for 10 min means at which condition resonance occurred. The MR elastomer with connecting aasembly was clamped to the vibration table shown in figure 3.1. The vibration table was actuated by FFT that converted the rotary motion of the motor shaft into linear to and fro motion. The elastomer was tested with zero load, 10N, 20N and 30N load. The force experienced in the MR elastomer and connecting aasembly, was sensed by upper accelerometer fixed at the top of the set-up and lower accelerometer placed near or on the vibration exciter as shown in Fig. 5. The test was performed with all the samples of isotropic and anisotropic MRE with zero load, 10N, 20N and 30N load respectively.

IV. RESULT AND DISCUSSION

There is a fraction changes in transmissibility in all samples as per the load increases but generally in isotropic MRE as the load increases transmissibility increases and in anisotropic MRE there is decrease in transmissibility as the load increases. Maximum variation in transmissibility occurs in isotropic and anisotropic MRE with 30 gm iron particles because it shows maximum vibration absorption among all samples. It is shown in Fig. 6.

There is reduction in upper amplitudes in all samples as per the load increases. In isotropic MRE with 30 gm iron particles there is less reduction in upper amplitude and anisotropic MRE with 30 gm iron particles shows opposite changes among all MRE samples. It is shown in Fig. 7.

There is reduction in lower amplitudes in all samples as per the load increases. In isotropic MRE with 30 gm iron particles there is increase in lower amplitude and anisotropic MRE with 30 gm iron particles shows reduction in amplitude at 10N after it shows increase in amplitude and again it slightly decreases. It is shown in Fig. 8.

Table 2 : % of Vibration Absorption for Different Load

Samples	Frequency	Load	Amplitude		Transmissibility	% of vibration absoption
1	48.3	Zero	Upper	7.13	1.3436	25.574
			Lower	9.58		
		10N	Upper	6.89	1.3687	26.935
			Lower	9.43		
		20N	Upper	6.78	1.3702	27.018
			Lower	9.29		
2	48.3	Zero	Upper	6.91	1.3719	27.110
			Lower	9.48		
		10N	Upper	6.89	1.3672	26.858
			Lower	9.42		
		20N	Upper	6.66	1.3529	26.082
			Lower	9.01		
3	48.3	Zero	Upper	6.48	1.4182	29.489
			Lower	9.19		
		10N	Upper	6.41	1.4477	30.927
			Lower	9.28		
		20N	Upper	6.39	1.4570	31.364
			Lower	9.31		
4	48.3	Zero	Upper	5.26	1.7224	41.943
			Lower	9.06		
		10N	Upper	5.12	1.6289	38.609
			Lower	8.34		
		20N	Upper	5.55	1.6072	37.780
			Lower	8.92		
5	48.3	Zero	Upper	7.38	1.2615	20.730
			Lower	9.31		
		10N	Upper	7.27	1.2641	20.892
			Lower	9.19		
		20N	Upper	6.74	1.2715	21.354
			Lower	8.57		
6	48.3	Zero	Upper	6.77	1.2806	21.915
			Lower	8.67		
		10N	Upper	6.39	1.2770	21.691
			Lower	8.16		
		20N	Upper	5.71	1.2750	21.566
			Lower	7.28		
7	48.3	Zero	Upper	7.19	1.2949	22.771
			Lower	9.31		
		10N	Upper	7.08	1.2980	22.960
			Lower	9.19		
		20N	Upper	6.59	1.3005	23.104
			Lower	8.57		

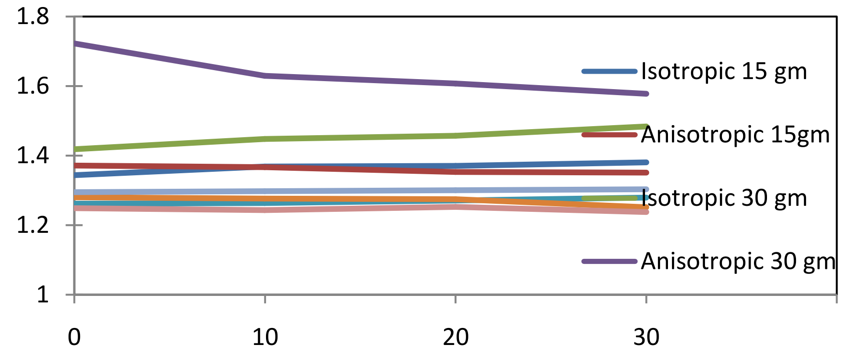

Figure 6: Load vs Transmissibility (10KN Load)

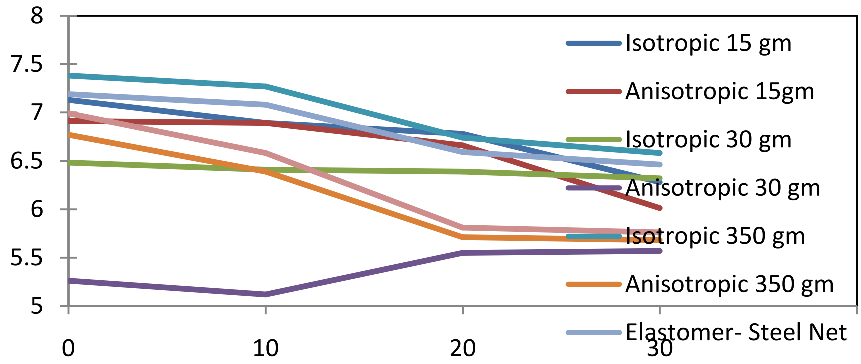

Figure 7: Load vs Transmissibility (20KN Load)

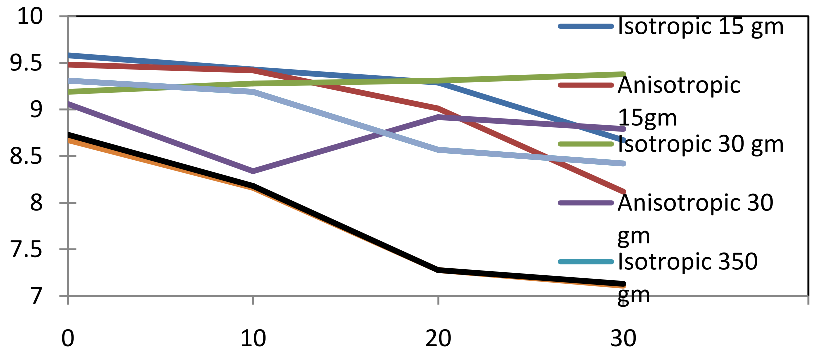

Figure 8: Load vs Transmissibility (30KN Load)

V. CONCLUSION

As when the MR elastomer was tested without magnetic field under zero load, 10N load, 20N load and 30N load respectively reduced the amplitude of vibration at same frequency also transmissibility and percentage of vibration absorption increases with increases the load. And as when the MR damper was tested with magnetic field under zero load, 10N load, 20N load and 30N load respectively transmissibility and percentage of vibration absorption decreases with increases the load. The best results of percentage of vibration control is obtained with fabrication of anisotropic and isotropic MRE with 30 gm iron particle behind that anisotropic and isotropic MRE with 15 gm iron particle have good results of vibration control. It observed that when we increases the percentages of iron particle in same MRE sample from normal limit transmissibility and percentage of vibration absorption decreases. If we put thin steel net in place of iron particle layer by layer in between layer of elastomer shows moderate results of vibration control.

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