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EXPERIMENTAL EVALUATION OF PERFORMANCE OF MAGNETORHEOLOGICAL ELASTOMERS BUSHES

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ABSTRACT

Present work deals with the study of preparation method of Magnetorheological Elastomer and testing it under different loading conditions by varying applied magnetic field. Micron size iron particles are used for the preparation of MRE bush in order to increase number of iron particles in elastomer matrix. It improves performance of MRE bush. Four different MRE bushes are prepared by using two different compositions and their performances have been studied under different loading conditions and applied magnetic field.

KEYWORDS: Curing, MRE, Smart Material, Response Analysis

INTRODUCTION

Smart materials are materials with properties that can be significantly altered in a controlled fashion by external stimuli, such as stress, temperature, pH, moisture, electric or magnetic fields. Especially materials, which can respond to the changes in their environment in a very short time, are currently developed. An elastomer comprising a matrix interspersed with µ size ferromagnetic particles is known as a Magnetorheological Elastomer (MRE). The rheological properties of MREs (the deformation and flow behavior under stress) are altered by the application of an external magnetic field [1]. The characteristic response of MRE is influenced by many factors including; the elastomer matrix, the size, distribution, composition and percentage volume of the ferromagnetic particles, and whether the ferromagnetic particles are aligned in chains or randomly dispersed. MRE's are used to change the natural frequency of the system by changing the stiffness of the structure. During the past two decades the interest in intelligent material based solutions has shown a huge growth. In this study dynamic response of the MRE bush has been presented. Comparison has been done between MRE bush cured with magnetic field and without magnetic field by testing under different loads by varying applied magnetic field.

PREPARATION OF MRE BUSHES

Total four MRE Bushes were prepared using two compositions of its ingredients, Sylgard's 184 silicone elastomer as a matrix, carbonyl iron particles with size of 5 µ, and a small amount of curing agent [2,3,4]. The compositions used for preparation of MREs are as shown in Table 1. In order to prepare these MRE Bushes all ingredients including iron particles were thoroughly blended with stirrer. Then the mixture was poured into an aluminum mould. A permanent magnets having field strength of 0.07 T were applied on wall of mould. After that, mould was placed in oven for 50 minutes at 85^0 C. MRE Bushes prepared by first and second composition without application of magnetic field during curing process is designated by 184 $nMRE_1$ and 184 $nMRE_2$ (i.e. Elastomer Ferromagnet Composites) respectively while MRE Bushes prepared by first and second composition with application of 0.07 T magnetic field during curing process is designated by 184 $mMRE_1$ and 184 $mMRE_2$ respectively. All MRE Bushes have been shown in fig. 1.

Table 1: Composition of MRE Bushes

MRE Name	Silicone Rubber (% by Volume)	Size of Iron Particle (μ)	Iron Particle (% by Volume)	Curing Agent (% by Volume)
184 $nMRE_1$	65	5	28.5	6.5
184 $nMRE_2$	57	5	37.3	5.7
184 $mMRE_1$	65	5	28.5	6.5
184 $mMRE_2$	57	5	37.3	5.7

Figure 1: Final Solid MRE Bushes

TESTING OF MRE BUSHES

Dynamic response of four Bushes, i.e. 184 $nMRE_1$, 184 $nMRE_2$, 184 $mMRE_1$ and 184 $mMRE_2$ has been studied. Test set up required for testing MRE bush was fabricated as shown in fig.2 along with various instruments like accelerometers, FFT analyzer, Data acquisition and analysis software. This set up also includes the exciter, base plate and two accelerometers. MRE bush was fixed between two stainless steel housing. The arrangement was made to place and vary the distance between permanent magnets in top and bottom frame. Load was applied over top surface of MRE Bush. One Accelerometer was mounted over bottom frame for measuring the excitations coming from the exciter. Second Accelerometer was mounted over the top frame indicating vibration level in absence of magnetic field and by varying (0 T, 0.06 T and 0.12 T) magnetic field for All MRE Bushes.

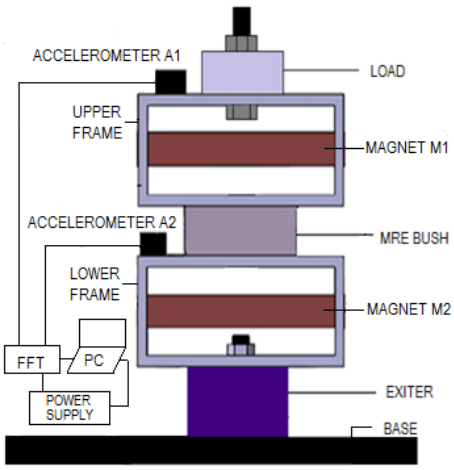

Figure 2: Test Set Up for Dynamic Response Analysis of MRE Bush

RESULTS AND DISCUSSIONS

During testing various data were recorded and from that the frequency responses (acceleration versus frequency) of all four bushes were plotted for masses of 0 N, 2 N, and 4 N with application of 0 T, 0.06 T and 0.12 T magnetic fields. Sample graphs of 184 nMRE1 with 0 N load are shown in fig.3, 4 & 5. x coordinate of cursor value at right side of each figure indicates natural frequency of 184 nMRE$_1$ at that particular condition. Here natural frequency at 0 T magnetic field is indicated by $f_{0,}$ at 0.06 T magnetic field is indicated by f_1 and the same with 0.12 T magnetic field is indicated by f_2.

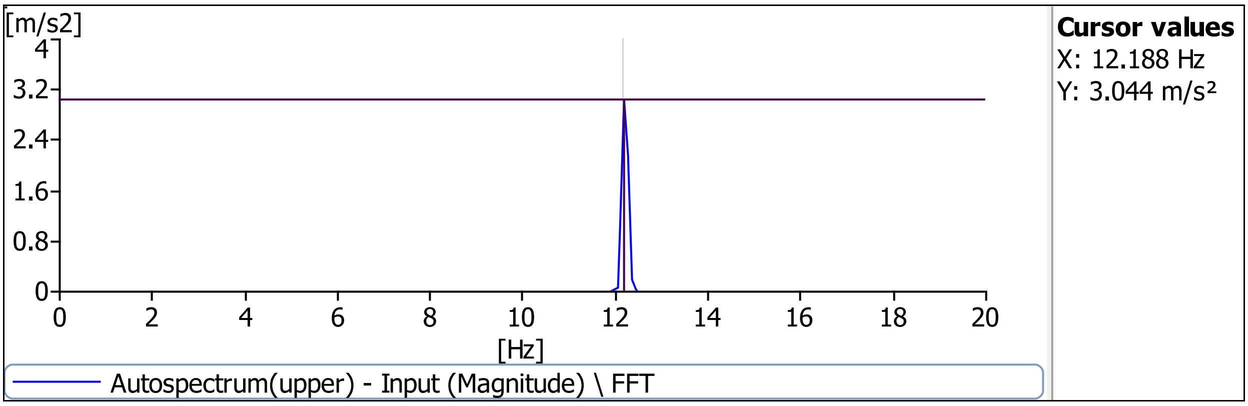

Figure 3: 184 nMRE$_1$ Response with 0 N Mass and 0 T Magnetic Field

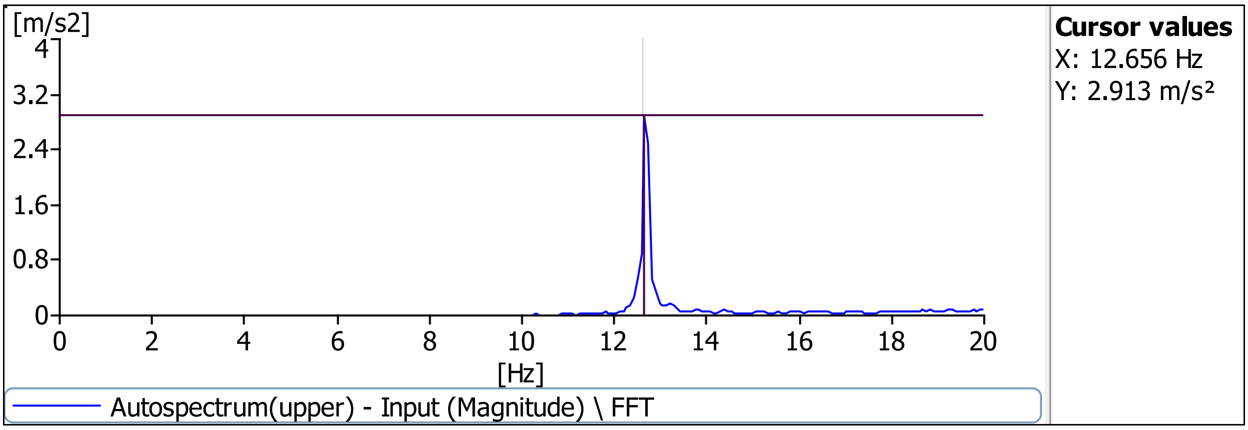

Figure 4: 184 nMRE$_1$ Response with 0 N Mass and 0.06 T Magnetic Field

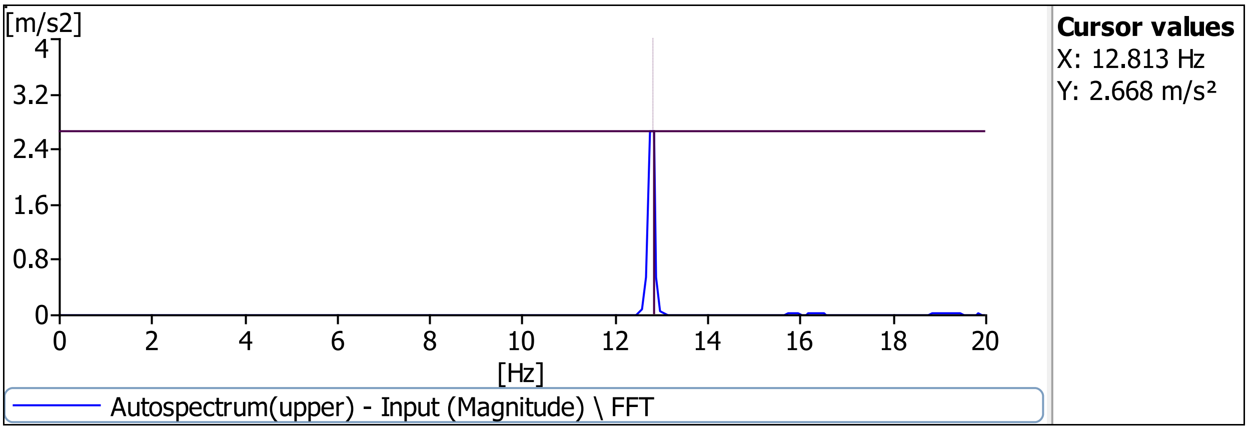

Figure 5: 184 nMRE$_1$ Response with 0 N Mass and 0.12 T Magnetic Field

For Load=0 N the natural frequency at 0 T magnetic field $f_0 = 12.19\ Hz$, at 0.06 T magnetic field $f_1 = 12.66\ Hz$ and at 0.12 T magnetic field $f_2 = 12.81\ Hz$. From the graphs values of frequencies f_0, f_1 and f_2 for different loading conditions of all four bushes were obtained. In all 36 readings were taken for different load and magnetic field conditions. The experimental results of sample readings are tabulated as shown in Table 2.

Table 2: Natural Frequencies of Bushes

Reading No.	Name of MR Bush	Load and Magnetic Field	Acceleration (m/s^2)	Natural Frequency (Hz)
1	184 nMRE$_1$	At 0 N and 0 T	3.04	12.19
2		At 0 N and 0.06 T	2.91	12.66
3		At 0 N and 0.12 T	2.66	12.81

For an MRE experiencing a shear force, fractional change in modulus $\Delta G\ /\ G_0$, is related to the fractional change in natural frequency $\Delta\omega/\omega_0$ [5], using,

$$\frac{\Delta\omega}{\omega_0} = \sqrt{1 + \frac{\Delta G}{G_0}} - 1 \qquad \text{------ (1)}$$

Solving for fractional change in modulus yields,

$$\frac{\Delta G}{G_0} = \left(\frac{\Delta\omega}{\omega_0} + 1\right)^2 - 1 \qquad \text{------ (2)}$$

Assuming that the equation for the shear modulus can be applied to the elastic modulus when the stress is applied uniaxial to the material, we calculated from obtained frequencies the values for fractional change in resonant frequency and modulus for different loads. Response of 184 nMRE$_1$ and 184 mMRE$_1$ to three different loads with 0 T, 0.06 T and 0.12 T magnetic fields is combined in following graphs.

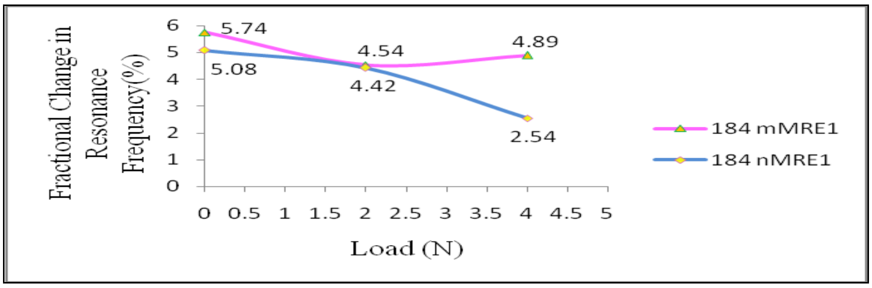

Figure 6: Fractional Change in Resonance Frequency v/s Load of 184 nMRE$_1$ and mMRE$_1$

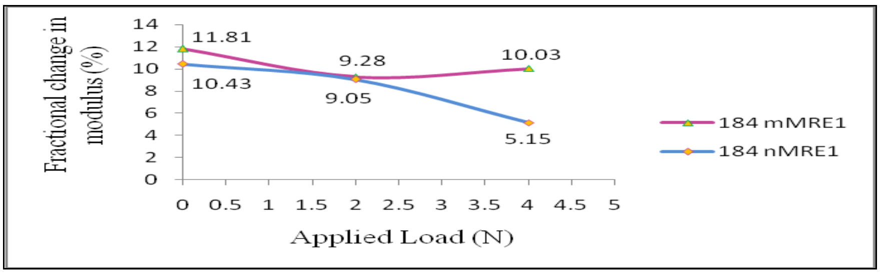

Figure7: Fractional Change in Modulus v/s Applied Load of 184 nMRE$_1$ and mMRE$_1$

From fig. 6 and 7 it is seen that resonant frequency of MRE bush cured without magnetic field is lower than the equivalent MRE bush cured in magnetic field. For 184 nMRE$_{1,}$ the average change of natural frequency is 4.01 % with worst case value 2.54 %. The average percentage change for the184 $mMRE_1$ is 5.05 %. For 184 $nMRE_1$ the average change in modulus is 8.21 % with worst case value of 5.15 %. The average change in modulus for the184 $mMRE_1$ is 10.37 %. As load goes on increasing natural frequency goes on decreases but its value always remains greater when magnetic field is applied. The response of 184 $mMRE_1$ to increasing magnetic field is remarkable as compared with 184 $nMRE_1$. Also it is observed that natural frequency of 184 $mMRE_1$ is always greater than that of 184 $nMRE_1$. We got discrepancy for 184 $mMRE_1$ at 4 N applied load because system was in unbalance state at 4 N applied load so that system could not vibrate in single degree of freedom.

Response of 184 $nMRE_2$ and 184 $mMRE_2$ to three different loads with 0 T, 0.06 T and 0.12 T magnetic fields is combined in following graphs.

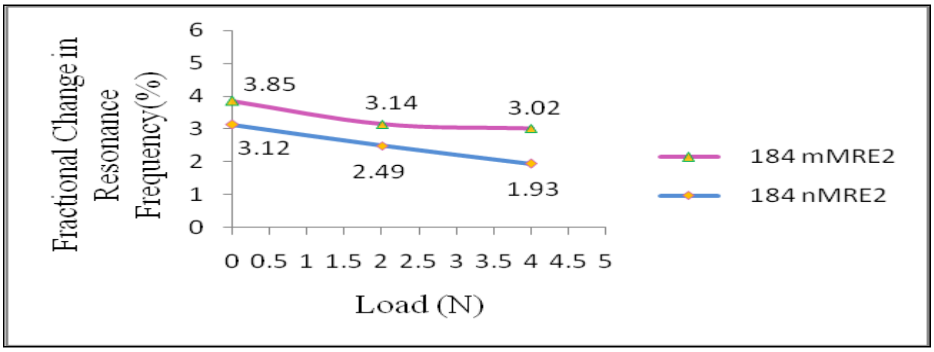

Figure 8: Fractional Change in Resonance Frequency v/s Load of 184 $nMRE_2$ and $mMRE_2$

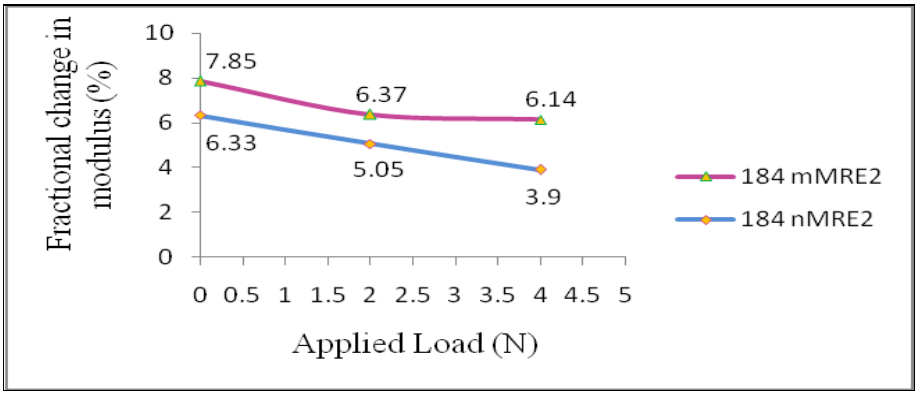

Figure 9: Fractional Change in Modulus v/s Applied Load of 184 $nMRE_2$ and $mMRE_2$

From fig. 8 and 9 it is seen that resonant frequency of MRE cured without magnetic field is lower than the equivalent MRE cured in magnetic field. For 184 $nMRE_{2,}$ the average change of natural frequency is 2.51 %. The average percentage change for the184 $mMRE_2$ is 3.33 %. For 184 $nMRE_2$ the average change in modulus is 5.09 % with worst case value of 3.90 %. The average change in modulus for the184 $mMRE_2$ is 6.78 %.

Response of change in modulus versus applied magnetic field of 184 $nMRE_1$ and 184 $mMRE_1$ with three magnetic fields, 0 T, 0.06 T and 0.12 T are also combined in following graph. From fig. 10 it is seen that change in modulus of MRE cured without magnetic field is lower than the equivalent MRE cured in magnetic field. For 184 $nMRE_{1,}$ the average change in modulus is 2.97 % with worst case value of 0 %. The average percentage change for the184 $mMRE_1$ is 9.69 %. As magnetic field goes on increasing change in modulus goes on increases. The response of 184 $mMRE_1$ to increasing magnetic field is remarkable as compared with 184 $nMRE_1$. Also it is observed that change in modulus of 184 $mMRE_1$ is always greater than that of 184 $nMRE_1$.

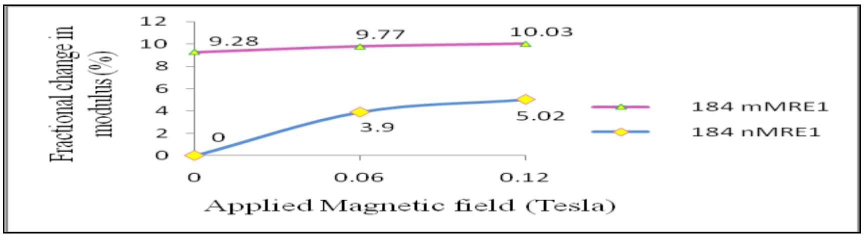

Figure 10: Fractional Change in Modulus v/s Applied Magnetic Field of 184 $nMRE_1$and $mMRE_1$

Response of change in modulus versus applied magnetic field of 184 $nMRE_2$ and 184 $mMRE_2$ with three magnetic fields, 0 T, 0.06 T and 0.12 T are combined in following graph. From fig.11 it is seen that for 184 $nMRE_{2,}$ the average change in modulus is 2.12 % with worst case value of 1.29 %. The average percentage change for the184 $mMRE_2$ is 10.01 % with worst case value of 3.66 %.

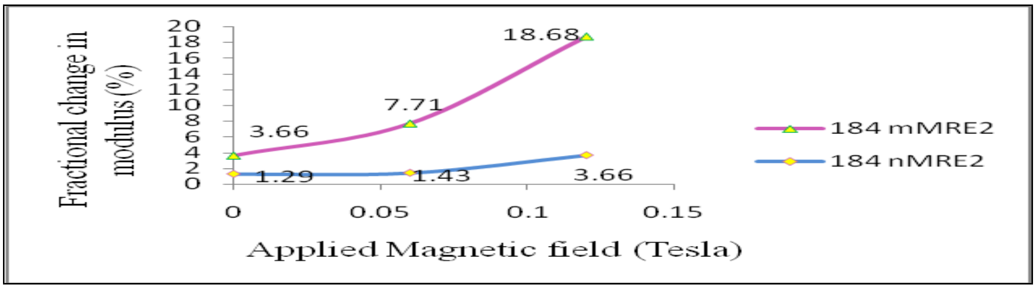

Figure 11: Fractional Change in Modulus v/s Applied Magnetic Field of 184 $nMRE_2$and $mMRE_2$

CONCLUSIONS

The results obtained in this study shows that due to applied magnetic field at the time of curing process magnetic particles get aligned into MRE bush which have a greater effect on the change in modulus. Also MR Elastomer gives satisfactory response to applied magnetic field. Its modulus of elasticity varies with magnetic field. This characteristic of MRE bush could become important feature in automotive semi-active suspension systems.

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