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# A feasibility work on the applications of MRE to automotive components

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**Abstract.** A feasibility work on the application of magneto-rheological elastomers (MREs) to automotive components, such as engine mounts is presented. While vehicle components require the high resonance frequency in terms of ride quality and handling, it is required to have the low resonance frequency to isolate the incoming vibration. With the conventional automotive technologies, it is challenging to combine these two conflicting performance trade-offs, ride quality including handling, and NVH (noise, vibration and harshness). Over the last decades, MREs, one of the new emerging smart materials, have been widely used to resolve this technical limitation. For example, an advanced engine mount was developed by using MRE to isolate the vibration transmitting from engines. In this paper, we will focus on rear cross member bushes, which is a key component for isolating the vibration from the road, and demonstrate their improved performance by utilizing MRE. The resonance frequency shift induced by the stiffness change of MRE will be presented through the frequency response functions estimated by simulation result.

## 1. Introduction

Magnetorheological (MR) fluid, foam, elastomers are group of smart materials whose rheological properties can be controlled by magnetic field. One of smart material, MR Fluid is composed of silicone oil and magnetic particles, which allow controlling fluid flow in accordance with external magnetic field, thereby forming a very agile response to the flow of fluid and forming yield stress [1, 2 and 3]. Over the past decade, industrial and academic and commercialize research have been utilized in many vibration reduction systems using the MR fluid characteristics. For example, the landing gear system, vibration control of the bridge and washing machine, building damping system, vibration isolation system of the semi-conductor equipment as well as vehicle suspension, seat damper and so forth. In particular, MR Fluid dampers and mount as a semi-active system have been effectively reduced vibration by adjusting damping force [1, 7]. In spite of MR fluid advantages, it is impossible to derive significantly changes of vibration transmissibility on the vehicle by means of damping forces.

MR elastomer, which belongs to the MR material family, is a composite material with magnetic-sensitivity particles suspended or arranged within a non-magnetic elastomer matrix. With a magnetic

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field, the particles exhibit an MR effect, providing a field-dependent material property to the material, i.e. a controllable modulus and damping. Compared with MR fluids, MR elastomers overcome the problems that accompany the application of MR fluid, such as deposition, sealing issues and environmental pollution etc., which makes MR elastomers a favourable candidate for various and controllable vibration control application. MR elastomer consist of three basic components, e.g. polarized magnetic particles and elastomer/rubber matrix and additives materials (usually used silicon oil). Conventional matrix of MR elastomers is usually made of natural rubber or silicone rubber and are adjusted according to need as shown figure 1. In addition, MR elastomer classified into two groups, i.e. isotropic and anisotropic (or sometimes it is used aligned) MR elastomers, which attribute to different ways of curing. Firstly, three basic components, namely silicon rubber, silicone oil and iron particles, are mixed thoroughly into a homogenous mixture. The isotropic MR elastomer is cured without the presence of a magnetic field, while the anisotropic MR elastomer is cured with the action of a magnetic field [4, 12].

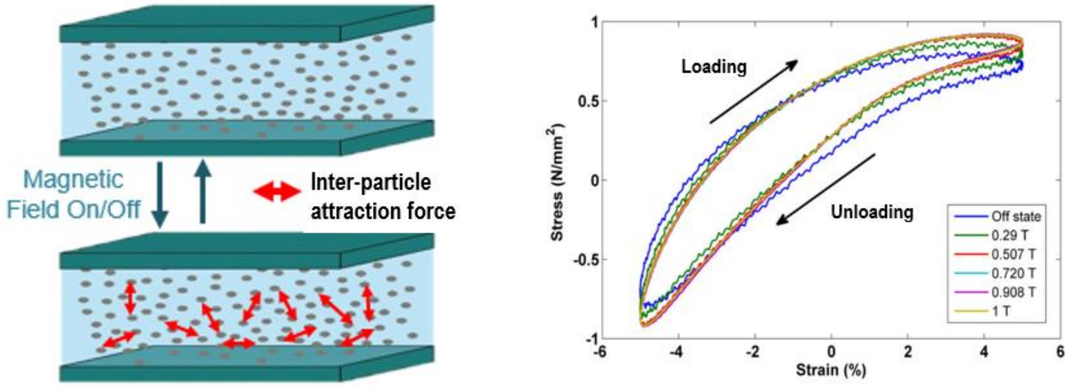


**Figure 1.** Principle and material characteristics of MR Elastomer.

In case of the passenger vehicle development, the passive type bush and mount have limited to satisfying both NVH (Noise, Vibration and Harshness) and ride, handling performance simultaneously. MR elastomer used as an alternative to overcome the limitation of conventional passive bush and mount, MR fluid mounts [2]. Based on the principles of MR elastomer, if the magnetic field switched off, the stiffness of the system reduced for NVH characteristics, on the contrary, if the magnetic field is applied, dynamic stiffness can be significantly increased then ride quality and handling performance will be improved. By utilizing the controllable characteristics (storage modulus and loss modulus) of MR elastomer, it improved and derived from the trade-off performance both NVH performance and ride quality, handling performance of the vehicle system. In this research, we will focus on rear cross member bushes, which are a key component for isolating the vibration from the road, and demonstrate their improved performance by utilizing the MR elastomer. The resonance frequency shift induced by the stiffness change of as shown in figure. 7. The aims to design and assess the stiffness change of MR elastomer will be presented through the frequency response estimated by simulation result.[4,5 and 11]

## 2. Fundamentals of MR Elastomer

Figure 2 illustrates three basic operation mode of the MR elastomer, in the compression modes, the direction of motion or vibration is parallel to line of magnetic induction while in the shear mode, the direction of motion is perpendicular to the line. Compared with the one in the compression mode, the MR elastomer in the shear mode accomplishes a smaller storage modulus and greater than MR effect and thus is widely utilized. Moreover, two types of particle arrangement both isotropic and anisotropic MR elastomers classified for the three basic operation modes.[4, 8] Therefore, different configurations found for device with isotropic and anisotropic MR elastomers, e.g. combination of field directions and aligned chain directions. Also sometimes MR elastomers that work in field active mode used to design various actuators. In shear mode devices, include vibration absorbers or vibration isolators and base isolators. Examples of squeeze mode devices are vibration absorbers, engineering mounts and compressive spring elements [5].

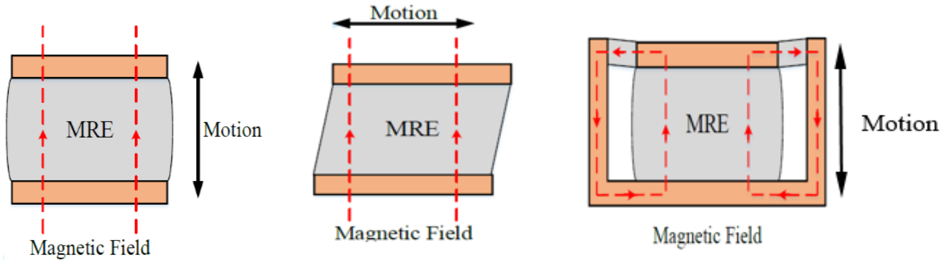


**Figure 2.** Three basic operation modes of MR elastomers [4,5,8, and 9]

The mechanical properties of MR elastomers are a combination of the matrix properties and the properties of the magnetic particles embedded in the matrix. It is recommend-using particles with a high saturation magnetization, because the maximum possible field induced MR effect occurs when the particles become magnetically saturated. According to rubber material, particle arrangement and iron particle content i.e., Carbonyl Iron Power, curing condition and mixing time and so on. MR effect could define as MR elastomer performance calculated from the sweep current. It is also experimental formula, which used widely as follows and the higher of MR effect, the higher dynamic rate. Figure 3 illustrates three moduli, i.e., shear modulus, storage modulus and loss modulus of MR effect for viscoelastic material including MR elastomer.

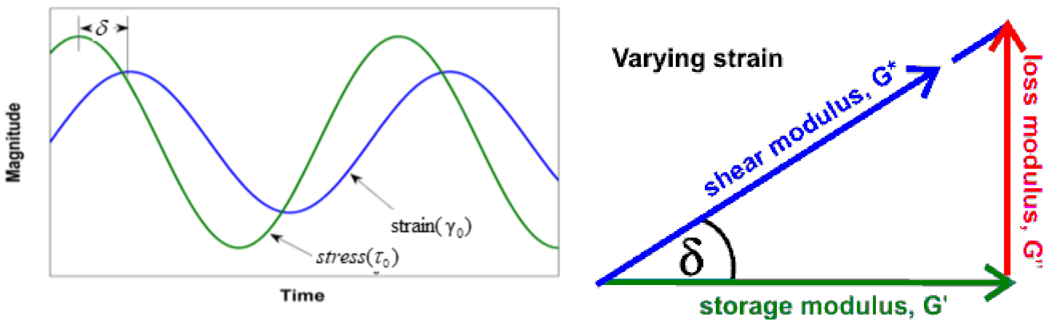


**Figure 3.** Illustrated of the shear modulus, storage modulus, loss modulus, of MR elastomer.

$$G^* = G' + i\,G'' \tag{1}$$

$$G' = G^* \cos\delta \quad \text{and} \quad G'' = G^* \sin\delta \;,\; \tan\delta = \frac{G''}{G'} \tag{2}$$

where $G^*$ is shear modulus, $G'$ is storage modulus(real part of shear modulus), $G''$ is loss modulus(imagery part of shear modulus), $\delta$ is defined phase angle respectively, as shown in figure 3. Thus, MR effect formula expressed as following:

$$\frac{G'_{max} - G'_0}{G'_0} \times 100 \quad (\%) \tag{3}$$

Where $G'_{max}$ is maximum on status of magnetic field, $G'_0$ is off state, i.e. not applied magnetic field.

## 3. Design of MRE Bush and Simulation Result.

### *3.1 Design and Magnetic Analysis of MRE bush for rear cross member*

Based on the passive type bush product analysis, we have designed MRE bush for rear cross member of 3D math models as shown in figure 8. These 3D models show isotropic view and quarter section view. In order to find optimal design and performance for magnetic flux, intensity, and magnetic force, we have to take into consider not only effective number of turns of coils but also MRE shape, arrangement and so forth. Therefore, we have conduct the optimal shape and MRE arrangement through a magnetic field analysis in five cases of 3D design model.

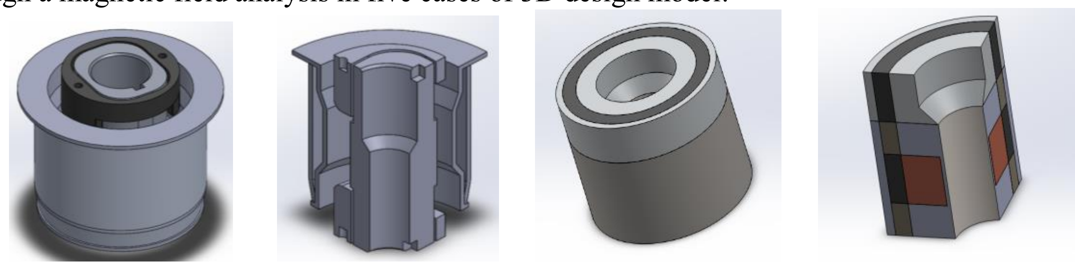

**Figure 5.** 3D model of cross member front and rear bush quarter section and assembly

With a magnetic field is the key role to the MRE bush working properly, it is worthwhile to study its magnetic field. According to Kirchhoff's magnetic law can be used to analyse the magnetic circuit design.[5] To verify the above theoretical calculation, a finite element analysis conduct with commercial software in ANSY 14.5 version. In order to find optimization feature of MR elastomer bush design, we have conduct magnetic analysis of five cases with 3D cad model design. Moreover, to maximize magnetic flux density and magnetic field intensity, we adapt two coils parallel structure model, which named proto #5 specification for optimization shape. From proto #5 design case, it increased to coil arrange to improve magnetic flux and field intensity. Thus, the magnetic flux path of MR elastomer was uniformly applied the magnetic field on three points, which located on MR elastomer. In addition, this model has a tendency to array of magnetic flux density and magnetic field formation compare with other four design. Therefore, we conclude fifth design for shape optimization design as shown in figure 6. [5, 6]

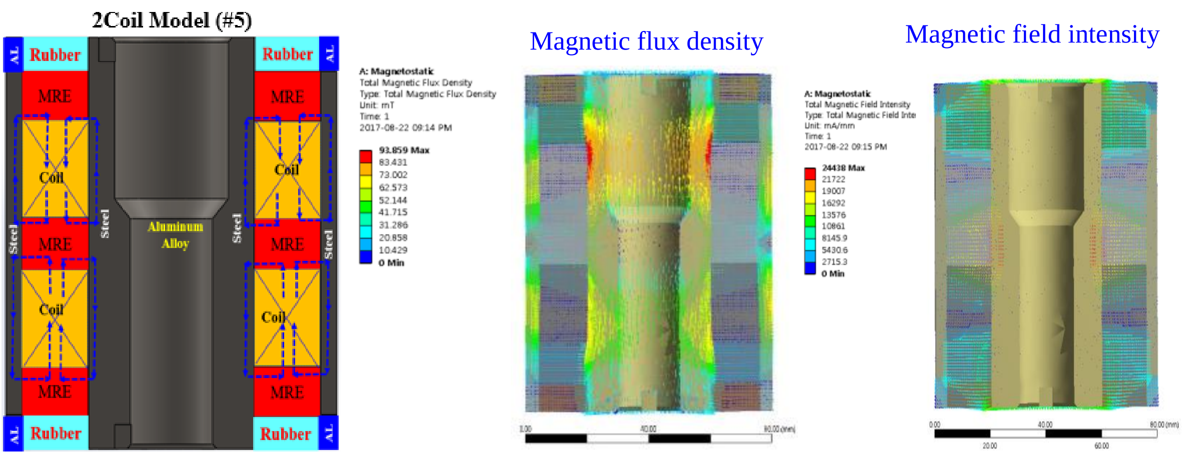


**Figure 6.** The final MRE bush design model with magnetic analysis

*3.2 Dynamic model of MR elastomer and frequency shifting*

The MR elastomer vibration isolator and absorbers may work in shear and squeeze mode or combined mode of those two. As variable stiffness devices, their effects alter resonance frequencies as following equation. [5, 6 and 11].

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad \text{and} \quad f_d = f_n\sqrt{1-\xi^2} \tag{4}$$

where, k and m are the stiffness and lumped mass, respectively. In addition to the damping in the system, such as by using MR fluid damper is less efficient in changing the natural frequency as equation (4). Where, $f_d$ is the damped natural frequency after adding damping into the system, and $\xi$ is the damping ratio of the system. The performance of the isolators achieved by evaluating their fundamental frequency, which relates to the stiffness of isolator. For a shear mode device with a cross-section area of an MR elastomer layer as rectangular square form expressed as equation (5).

$$K_s = K\frac{GA}{h} \quad \text{or} \quad K_s = \frac{EA}{nh} \tag{5}$$

where, G is the shear modulus of MR elastomer, A and h are the cross-section area and the thickness of the rubber layer, respectively, n is the number of MR elastomer layer in isolator. For squeeze mode of MR elastomer, the compressive stiffness $K_s$ expressed as equation (5). E is the compression modulus of the material. For single degree of freedom based and principle of vibration system shown in figure 7 (a) and (b), the vibration transmissibility expressed as equation (6).

$$T = \frac{F_T}{F_0} = \sqrt{\frac{1+(2\zeta\eta)^2}{(1-\eta^2)^2+(2\zeta\eta^2)}} \tag{6}$$

where, $\zeta$ is the damping ratio and $\eta$ is frequency ratio, $\eta = f/f_n$, $F_T$ is the transmitted force, $F_0$ is the excited force, respectively. The resonance frequency shift induced by the stiffness change of MRE will be presented through the frequency response functions estimated by simulation result for transmissibility as well as phase angle changed as shown in figure 7. After verify not only to evaluate for the MR elastomer performance of our proto design, but also the resonance frequency shift induced by the stiffness change of MRE will be presented through the frequency response functions estimated by simulation work and experimental measured result.

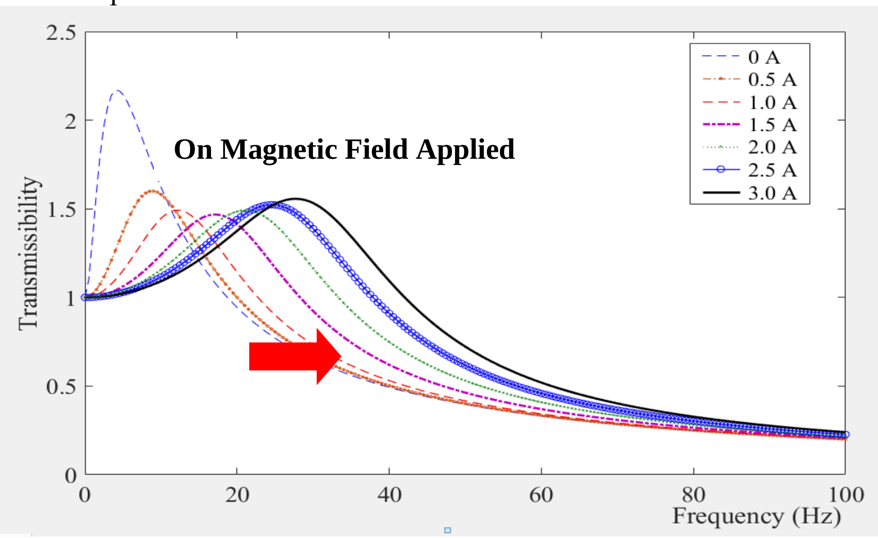


**Figure 7.** Simulation result of transmissibility with different currents

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## 4. Conclusion and Future work

This paper describes as a preliminary research and aims to confirm the feasibility of MR elastomer applicable to rear wheel drive vehicles, which through analysis of conventional passive type bushes on the rear cross member product. In addition, we have conduct literature review for MR elastomer basic theory, which is a key component for isolating the vibration from the excited vibration. Thus, we will ongoing to research not only MRE bush design but also to find optimization shape through case study of magnetic analysis. From our initial research, we will verify MR elastomer bush design and shape optimization. Furthermore, we will fabricate a proto design of the rear cross member bush by utilizing the MR elastomer. Then after will verify the MR elastomer performance of our proto design, as well as the resonance frequency shift induced by the stiffness change will be presented through the frequency response functions estimated by simulation work and experimental measured result.

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