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# Computational Validation of Magnetorheological Elastomers for Engine Mount Application

**Ismail Ladipo, Fadly Jashi Darsivan, Waleed Feekry Faris**

***Abstract---* *Magnetorheological Elastomers (MREs) are a class of smart materials whose potentials in engineering applications have been attracting attention in the last few decades. In this study, a rheological model for MRE and its dynamic characteriza-tion as engine mounts is presented. The use of magnetic field in controlling the dynamic stiffness and damping modulus of the engine mounts in a quarter car model is simulated. The vibration level of the MRE engine mount is compared with Passive rubber mounts. The results show an improved performance with a reduction in relative displacement in the low frequency range. Sensitivity analysis technique is used to compare the MRE mount parameters to improve its performance. The adaptive MRE mounts could be extended to other applications in which vibration isolation is required.***

***Keywords: Engine mounts; Magnetorheological Elastomers (MREs); Smart materials,***

## 1 INTRODUCTION

The limit level of rubber mounts in reducing vibration in automobiles has long been exceeded. Since the engine mounts system is the largest concentration of mass in the automobile, these changes to engine mounts are unavoidable in modern cars. Table 1 describe engine mount system requirement [1].

Car manufacturers usually design cars based on frequencies which they are more likely to travel. Some cars have engines designed for high speed (high frequencies; typically, from 30-250Hz), while other cars are design for low speed (low frequencies; typically, 0-30Hz) [2]. Engine mounts are required to be adaptive to these conflicting frequencies requirements.

**Table 1: Engine Mounts System Requirements**

| Excitation source | Frequency (Hz) | Solution | Requirement |
|---|---|---|---|
| Unbalance engine<br>disturbance force | 25-250<br>40-400 | Isolation | Low damping<br>Low stiffness |
| Engine shake<br>Resonance | <25<br><30 | Prevention | High damping<br>High stiffness |

Rivin [3] reported that for the necessary improvements for passive mounts, it is necessary to use mounts with constant natural frequency, variable stiffness, high internal damping, amplitude dependent dynamic stiffness and damping modulus, switchable properties between frequencies and reduced transmissibility at high frequencies.

These mounts characteristics can be met by the properties of Magnetorheological Elastomers (MREs). MREs are used in various devices in engineering applications. This range of applications includes: vibration absorbers and isolators [4], base isolators for applications in civil engineering structures [6] sandwich beams [7] and sensing devices [8]. There are two types of MREs: anisotropic and isotropic [9]. The difference is due to curing in the presence of magnetic during fabrication [10]. They consist of magnetic ore such as silicon, iron ore embedded in natural rubber [11].

The dynamic stiffness and damping modulus of MREs are the two mechanical properties that can be controlled by external magnetic field [12]. Theoretical descriptions of this materials in different engineering applications is still however limited [13]. Li et al. [13] established the limited applications of MREs as an alternative to rubber mounts in engine mounts [15]. Jeong et al. [15] designed the geometry and uses a 3A current which gives a magnetic field value of 0.287T.

This research utilizes the MRE model reported in the study by Li et al. [16] which is a combination of kelvin-Voigt model and an additional damper [17-20]. Collette et al. [21] used MRE as an Isolator. A linear relationship between the applied magnetic field and the dynamic characteristics (dynamic stiffness and damping modulus) of MRE Isolator reported in [11] was adopted.

The objectives of this paper are outlined as: development of the dynamic analysis of a four-parameter model for MREs. Comparison between the three-parameter model and the developed four-parameter model using transmissibility plots. The developed MRE model is used in a quarter car model and compared in performance with rubber mounts. The use of magnetic field to tune the MRE mounts to obtain even better results makes performance analysis a necessity. Sensitivity Analysis (SA) is used for prioritising these parameters.

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**Ismail Ladipo,** Department of Mechanical and Mechatronics Engineering, Higher Colleges of Technology, UAE. (E-mail: iladipo@hct.ac.ae)

**Fadly Jashi Darsivan,** Department of Mechanical Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia.

**Waleed Feekry Faris** Department of Mechanical Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia.

## 2 RHEOLOGICAL MODELS

MREs models can be divided into rheological and phenomenological models [2-4]. Rheological models [5-8] uses mechanical springs and dampers. The model presented here is four-parameter model (modification of existing model) that has shown good performance results in other applications [9].

Elastomers (rubbers) are usually represented with three-parameter Kelvin-Voigt model shown in Figure 1. The adopted model (modification of the Kelvin-Voigt model) is shown in Figure 2.

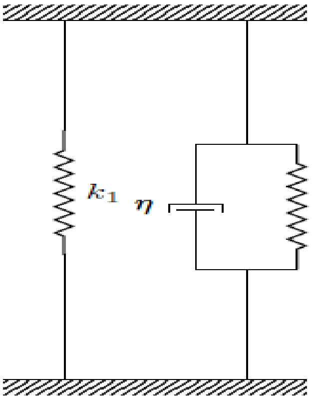

**Fig. 1: MREs Three-parameter model**

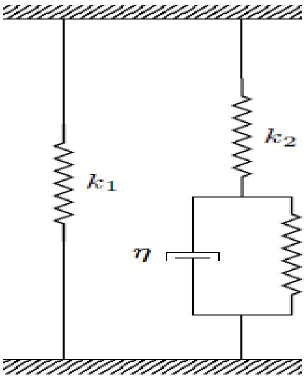

**Fig. 2: MREs Four-parameter model**

However, to use the adopted model (Four-parameter) for MRE mounts, mathematical analysis of the four-parameter is required. The stress and strain relationship are given as

$$\left(\frac{\sigma}{\varepsilon}\right)^{*}=\frac{(k_1k_3+k_2k_3+k_1k_2)[(k_1+k_2)^2+\eta^2\omega^2]+\eta^2\omega^2k_1^{\,2}}{(k_1+k_2)[(k_1+k_2)^2+\eta^2\omega^2]} \qquad (1)$$

The transition frequency temperature is the phase between the solid and liquid phase for elastomeric materials and given as [10]

$$\omega_t^{\,2}=\frac{k_2+k_3}{\eta^2}\left(\frac{k_2k_1+k_3k_2+k_3k_1}{k_2+k_1}\right) \qquad (2)$$

The dynamic stiffness and damping modulus changes in frequency and amplitude of excitation are shown in Figure 3 and Figure 4 respectively. The dynamic stiffness of the four-parameter has higher values when compared to the three-parameter model.

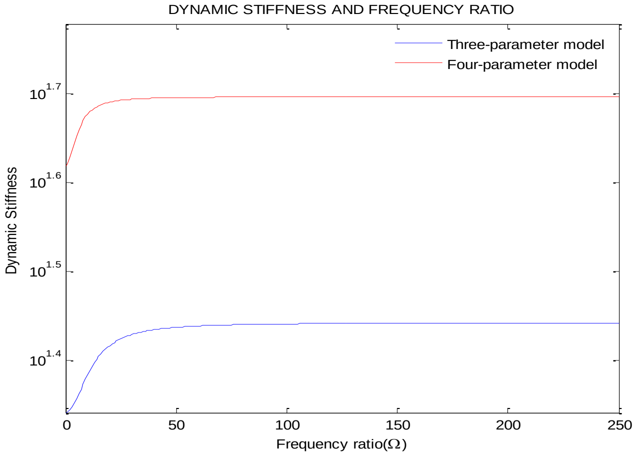

**Fig. 3: Dynamic stiffness**

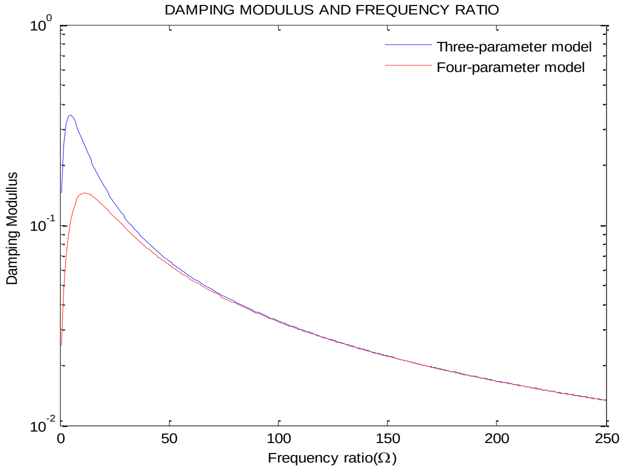

**Fig. 4: Damping modulus**

The damping modulus of the four-parameter is lesser at low frequency when compared to the three-parameter model. The transmissibility of the three-parameter is compared with the four-parameter model and plotted in Figure 5.

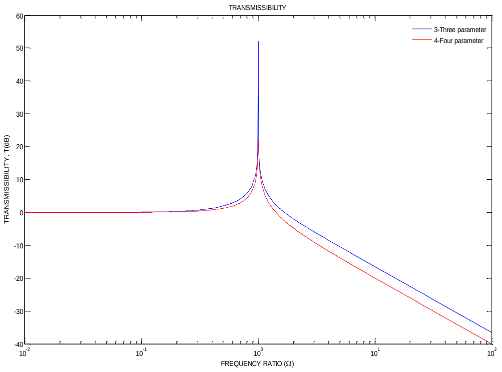

**Fig. 5: Transmissibility plot for three-parameter and four-parameter model**

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Using the criteria in [11], it is observed that the transmissibility of four-parameter model is lower than that of three-parameter model.

## 3 VEHICLE MODEL SIMULATION

The Passive rubber mount is a Kelvin-Voight model with two-parameters. Among the different car models, the quarter car model is also an important model [12]. The passive rubber mounts and the MRE mounts models in a quarter car are shown in Figure 6 and Figure 7.

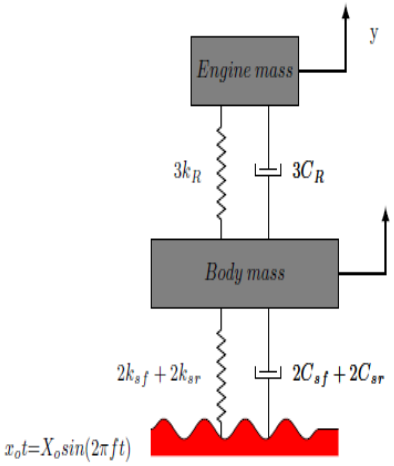

**Fig. 6: Quarter car model using Passive mounts**

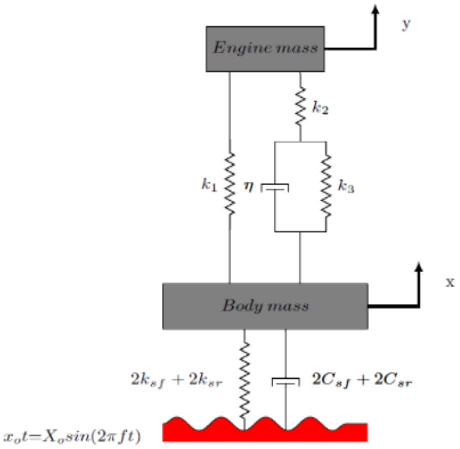

**Fig. 7: Quarter car model using MRE mounts**

The performance of the engine mounts models in the vehicle system is achieved using the relative displacement at low frequencies [13]. The parameters selected for the quarter car and mounts are presented [13].

## 4 RESULTS AND DISCUSSION

### *Frequency Decomposition*

Detailed submission guidelines can be found on the journal web pages. All authors are responsible for understanding these guidelines before submitting their manuscript.

### *4.1 Low Frequency*

The dynamic stiffness, amplitude and low frequencies relationship for passive rubber and MRE mount are shown in Figure 8 and Figure 9 respectively.

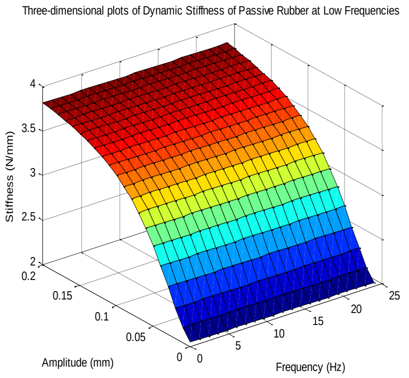

**Fig. 8: Three-dimensional plots of dynamic stiffness of MRE mount**

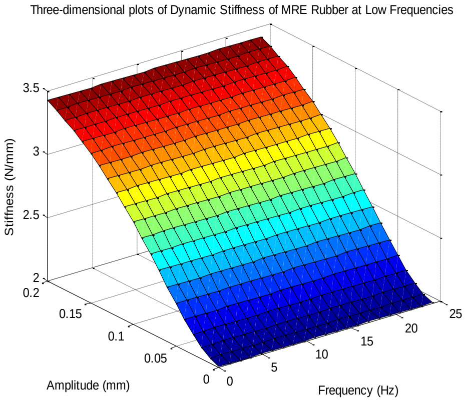

**Fig. 9: Three-dimensional plots of dynamic stiffness of Passive mount**

The dynamic stiffness shows almost similar behaviour with changes in frequency and amplitude of excitation i.e. the dynamic stiffness decreases with increase in amplitude of excitation and increase with the increase of frequency

### *4.2 High Frequency*

The dynamic stiffness, amplitude and high frequencies relationship for passive rubber and MRE mount are shown in Figure 10 and Figure 11 respectively.

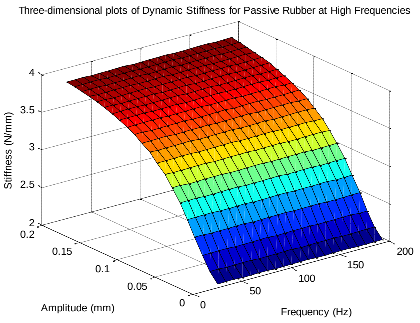

**Fig. 10: Three-dimensional plots of dynamic stiffness of MRE mount**

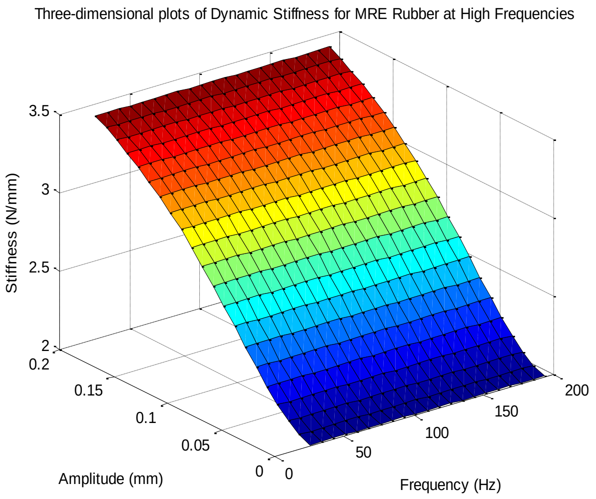

**Fig. 11: Three-dimensional plots of dynamic stiffness of MRE mount**

Using the engine relative displacements, the justification of using MRE mounts is seen in the reduction of the engine vibration. With 2.5*T* and 0.287*T* magnetic field values, there is more than 50% reduction in engine displacements as shown in Figure 12.

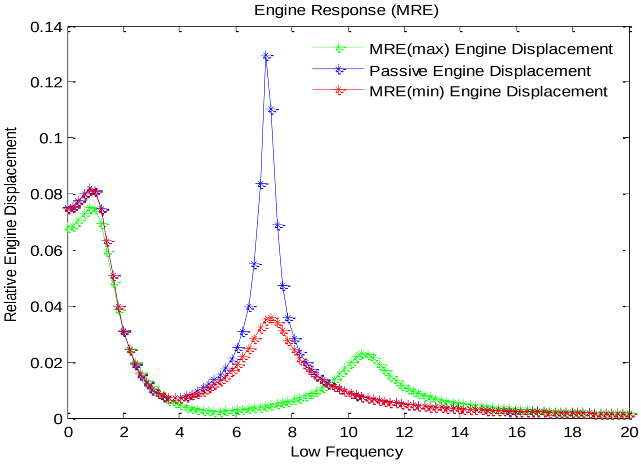

**Fig. 12: Relative displacements using magnetic field input (0.28T/2.5T)**

## 5 SENSITIVITY ANALYSIS

Also, following the revelations in Figure 12, there is the need to determine the sensitivity of the parameters use on the dynamic response of the engine mounts system. These parameters include: Magnetic field, Compositional stiffness are two parameters which needs to be studied. Since the research is analytical in nature, it is reported in literature that the Direct Observation of Simulations technique is appropriate for such research [14]. The relative sensitivity function is

$$S_T^P = \frac{P|_{NOP+\Delta T} - P|_{NOP}}{\Delta T} \qquad (3)$$

Based on overall strategies for sensitivity analysis [15], the aim of using sensitivity analysis is to vary the magnetic field and the compositional stiffness parameters. The effect of each of this is on the resonance frequency. The relative displacement is selected since the amplitude of vibration when either of the magnetic field or the compositional stiffness is tuned is important.

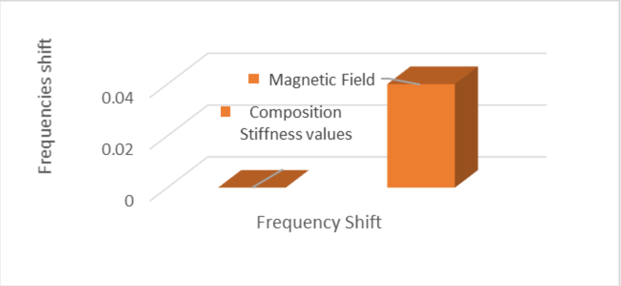

**Fig. 13: Effect of Magnetic field on the Frequencies shift**

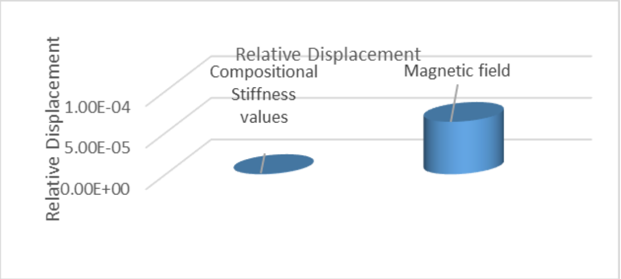

**Fig. 14: Effect of Compositional stiffness on Frequencies shift**

The magnetic field design around the engine mount system is more important than the characteristics stiffness as shown in Figure 13 and Figure 14.

## 6 CONCLUSION

The use of MRE mount as a substitute for passive mounts is at infancy stage in research. In this paper, dynamic stiffness and damping modulus of existing model and developed model are compared. It is seen that the four-parameter model gave better results. Using the developed computational model, the transmissibility function plot of both model is also presented. The simulation results show that the four-parameter model behave better than the three-parameter model.

Also, the passive rubber mount is compared with the developed MRE mount model using available experimental values. The dynamic stiffness of the MRE mount was lower while the damping modulus was higher. Considering the fact, that the damping modulus of the MREs can be further improved on by making it adaptive, a linear relationship between magnetic field and dynamic characteristics for the MRE is used. This enables an adaptive control on the MRE mount dynamic stiffness at higher frequency which is an important consideration for MRE engine mounts.

The varying parameters needed to improve the behaviors of the MRE engine mounts was studied. The compositional stiffness and the magnetic field being two important features. The design of the magnetic field proves more important than the stiffness and damping values of the MRE engine mounts. In respective of the stiffness and damping properties of the engine mounts, a good design (which is quite feasible) of the magnetic field will make it adaptive and perform better than passive rubber mounts. Future work is to optimize these parameters of the MRE mounts.

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