Magnetorheological Elastomer Stiffness Control for Tunable Vibration Isolator

Gigih Priyandoko
Department of Electrical Engineering,
Faculty of Engineering
Widyagama University
Malang, Indonesia
gigih@widyagama.ac.id

Tedi Kurniawan
Faculty of Mechanical Engineering
Univerisiti Malaysia Pahang
Pekan, Pahang, Malaysia
tedikurniawan@ump.edu.my

Efistein A. Naga
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia
efiarch94@gmail.com

***Abstract*—Most of the vibration isolator has fixed stiffness such as a passive vehicle mounting system. Objective of this research is to develop a Magneto-rheological Elastomer (MRE) as a vibration isolator; stiffness of vibration absorber can be controlled by an applied magnetic field. An MRE was fabricated by mixing silicon rubber, silicon oil and carbonyl iron particles together and then cured for 24 hours in a circular mold. The experimental result shows the absorption capacity of the developed MRE is better than the traditional MRE in time and frequency domains.**

Keywords—Magneto-rheological Elastomer, stiffness control, vibration isolators.

I. INTRODUCTION

Typically, in engineering there was a lot of heavy machinery or structure that vibrates whether on a small or big scale. Vibrations were harmful especially to structures because it can cause structures to fail under very high vibration. Various methods and materials have been proposed to reduce vibration. The methods are broadly classified as a passive, semi-active, or active system [1-5].

The passive methods use the rubber as the material of choice. However, passive systems are only effective over a very narrow frequency range. As the excitation frequency changes, the vibration reduction effect decreases or even collapses because of mistuning. The semi-active method combines the use of sensors and actuators to vary the properties of an isolator system. On the other hand, the active methods combine the use of sensors, actuators, additional electronics and fluids with controllable properties in solving these problems [6]. Disadvantages of the active vibration system are high consumption of energy and requirement of large activation force. The semi-active method is preferable due to its stability and reliability for both low and high-frequency vibrations. The high frequency requires low stiffness and low damping vibration isolator while the low-frequency vibration requires high stiffness and high damping vibration isolator [1,2,7–11].

The Magnetorheological Elastomers (MREs) are a class of smart materials whose stiffness and damping properties can be adaptively tuned to attenuate both low and high-frequency vibration [1–3,10,12]. The objective of this research is to develop a MRE as a tunable vibration isolator when different currents are applied to get different stiffness of the MRE.

II. MAGNETO-RHEOLOGICAL ELASTOMER

Magnetorheological fluids (MRF) state of matter can be changed with the use of different level of magnetic field. The fluids are composed of magnetic particles suspended in viscous fluid. It will have low viscosity with the absence of a magnetic field as the particle is not arranged. To enhance their magnetic susceptibility and reducing their tendency to form an aggregation, the magnetic particle of an MRFs are additionally covered with the special layer. Other substance such as anti-corrosion and anti-sedimentation substance, is added in a small amount. The influence of magnetic field causes changes in the physical properties of MRFs. The liquid returns to its baseline after absent of external magnetic field. One of the disadvantages of the MRFs is the sedimentation [1].

MREs, also known as a magneto-sensitive elastomer, are a class of smart materials whose stiffness and damping properties can be adaptively tuned to attenuate (reduce force/amplitude/effect) both low and high-frequency vibration. It is usually achieved by varying the magnetic flux input and in full active mode using sensors and actuators or semi-active mode [6,9,13]. Also, MREs have an improve properties in new structural materials. They are an intelligent composite material whose physical properties that are sensitive to the effect of the magnetic field. These changes are non-linear, which is completely reversible and occur within several milliseconds. Furthermore, MREs are a solid phase counterpart of MRFs. The liquid carrier is replaced by a solid material elastomer or rubber in the case under analysis. The polymeric matrix that is built inside the material were embedded with good magnetic properties material such as carbonyl-iron [3,14].

There are many benefits to using MRE. They consist of natural or synthetic rubber matrix interspersed with micron-sized (3 to 5 microns) ferromagnetic particles. An elastomer such as rubber is used, they are generally soft and deformable at room temperature. In conjunction with the particle structure, the magnetic particle cannot move freely within the matrix due to the elastomer. Thus, no sedimentation presents. On top of it, with the limitation particles movement result in a quicker response to a magnetic field than in MRFs [4]. MRFs durability is limited due to densification of liquid after many operating cycles. Agglomeration and sedimentation of magnetic particles is no longer a problem in case of MREs. Thermal stability is better where MREs and MRFs have a different operating range which is the essential difference between them [12,13,15].

The fabricated MRE samples are composed of carbonyl iron powder of an approximate diameter of 10 µm dispersed within the room-temperature vulcanizing (RTV) rubber matrix and silicon oil. They are fabricated based on the expertise acquired in the studies as shown in Figure 1.

III. VIBRATION ISOLATOR

A. Simulation

Finite Element Method Magnetics (FEMM) was an open source finite element analysis software package for solving electromagnetic problems. The program addresses 2D planar and 3D axisymmetric linear and nonlinear harmonic low frequency magnetic and magneto-static problems and linear electrostatic problems. This software was used to help in to design the magnetic circuit in the multi-sandwich vibration isolator by simulating the magnetic field in different types of conditions and parameters.

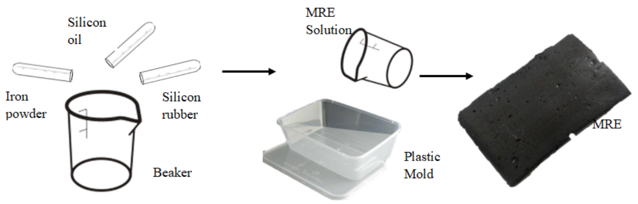

Fig. 1. Fabrication of MRE

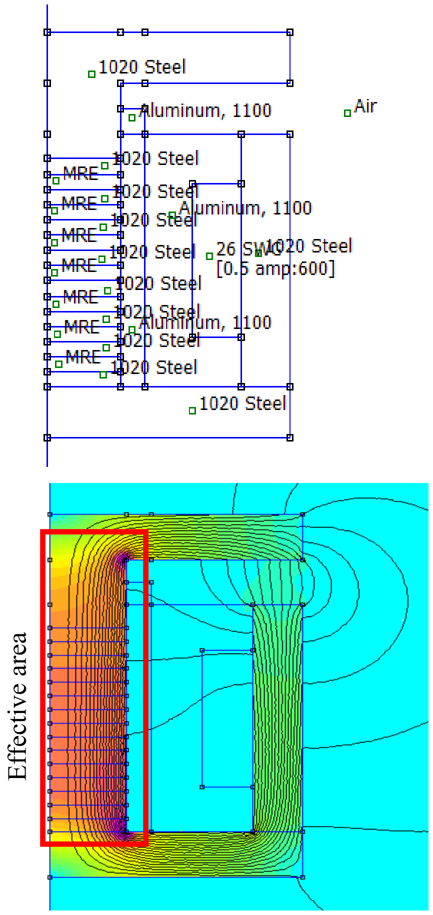

Fig. 2. Magnetics flux density contour plot

After defining the block properties and materials, the software can begin meshing the nodes to start simulating the magnetics circuit in the design that has been plotted and defined earlier. After defining the block properties and materials such as 1020 Steel, Aluminum 6061, copper coils and the air gaps, the FEMM simulation will look like as shown in Figure 2. The contour plot of magnetic flux density can be shown in the results of the FEMM as shown in the figure. The highest concentration of magnetic flux density was at the area where the MRE was located which was exactly the aim of this design was. This was also achieved by putting steel plates in between the MRE to make a kind of sandwich plate system to drag the magnetic field into the effective area highlighted in the figure. This result will be used to determine the design of the multi-sandwich vibration isolator regarding materials, dimensions of work-piece, and coil properties.

B. Fabrication

There were two main materials for the fabrication of the multi-sandwich vibration isolator which were plain carbon steel and aluminum. Plain carbon steel and aluminum were chosen based on its ferromagnetic properties and availability in the market. After each part of the vibration isolator has gone through in processes, the parts are assembled through methods of fitting using bolts and screw. A cross-sectional drawing shown in Figure 3.

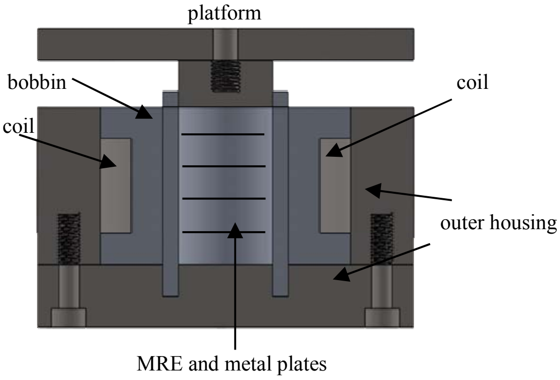

Fig. 3. Cross-sectional Diagram of Vibration Isolator

C. Test setup

Figure 4 shows the experimental setup of the vibration testing on MRE vibration isolator. The data acquisition system (DAQ) was connected to the laptop and the piezoelectric accelerometer to send the vibration signal to the laptop for processing. The DC power supply supplies current to the DC motor and the electromagnetic coil located inside the vibration isolator. The DC motor is used as disturbances was supplied with a constant voltage at 12 V throughout the whole experiment and mounted on top of the vibration isolator. Each time the experiment was conducted, the electromagnetic coil was supplied with 0, 1.0, 1.5 and 2.0 amperes while the DC motor was kept constant DC voltage at 12 V. The values and data are recorded inside the laptop using the DasyLab module. The data were analysed and plotted into graphs for ease of analysis and observing the changes in data. The data were split into the time domain and frequency domain for each current applied for better analysis.

IV. RESULTS AND DISCUSSION

Figure 5 shows the time response of the accelerometer on the vibration isolator when the current applied was 0 ampere. The vibration data are shown to be very useful in analyzing the vibration of the MRE vibration isolator. It can be seen that averagely the peak for the time domain are in the range of 0.05 m to 0.01 m. This data might not be representing the whole data because it has been scaled down to plot a clear graph. Figure 6 shows the frequency response of the accelerometer on the vibration isolator when the current applied was 0 ampere. From the figure, it can be seen that the highest peak obtained from the vibration isolator was 0.028 m at 1500 Hz.

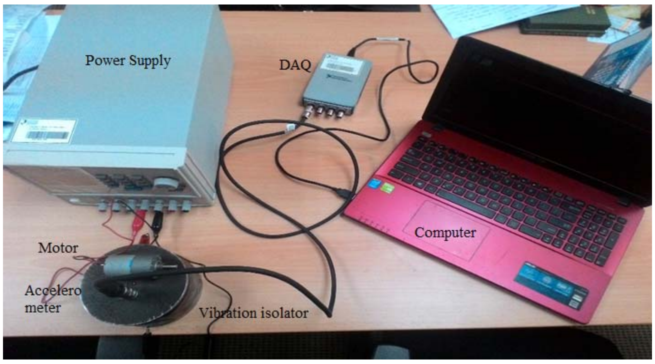

Fig. 4. The experimental setup

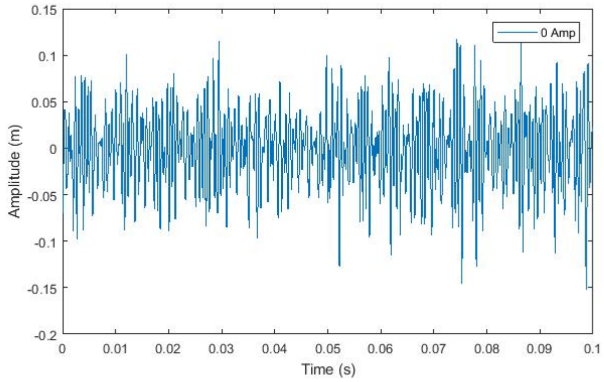

Fig. 5. Time response of vibration isolator at current 0 Amp.

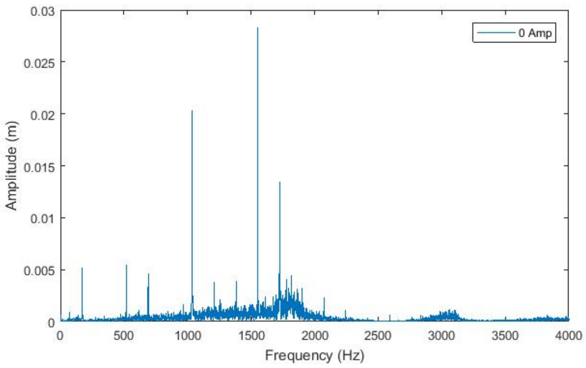

Fig. 6. Frequency response of vibration isolator at current 0 Amp.

When the current applied to the electromagnetic coils increases, this also increases the magnetic flux density in the effective area of the vibration isolator. This reacts with the carbonyl iron particles in the MRE and increases the stiffness of the MRE which in turn decreases the vibration on the MRE vibration isolator that was made by the 12V DC motor.

Figures 7-8 were the result of gathering data from all the time response graphs and frequency graphs and combining them into two graphs for time and frequency respectively to observe and analyze the difference in amplitude of vibration when the 12 V DC motor is providing vibration towards the MRE vibration isolator. From the graph, it was observed that there were slight differences in the amplitude of vibration with each increment of current applied. At some point it was hard to see just by observing the graph as it was not very clear for the time domain, so RMS value was calculated for the entire data for each current applied as shown in Table 1.

TABLE I. RMS VALUE BASED ON EXPERIMENTAL RESULTS

Current (Amp)	**RMS Value**	
	Time response	***Frequency response***
0.0	0.0398	0.0502
1.0	0.0397	0.0499
1.5	0.0391	0.0490
2.0	0.0390	0.0485

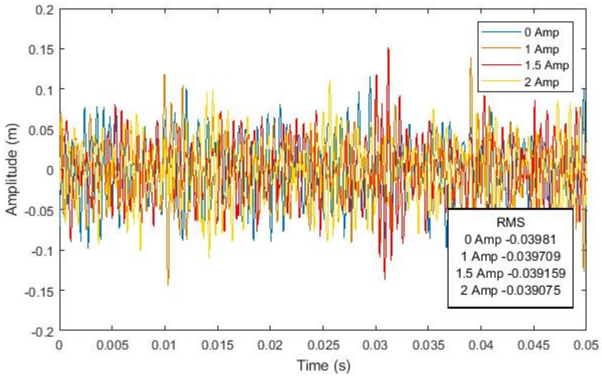

Fig. 7. Time response of vibration isolator at current 0-2 Amp.

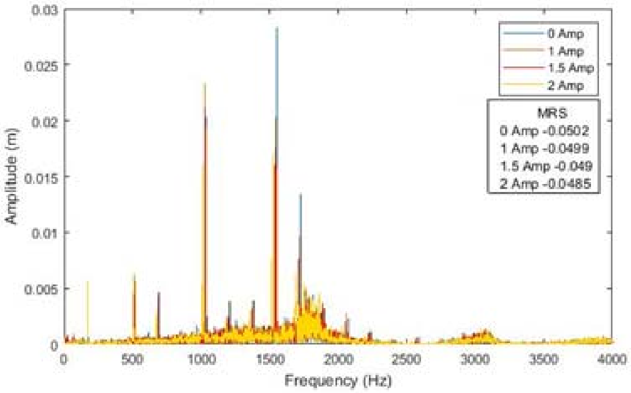

Fig. 8. Time response of vibration isolator at current 0-2 Amp.

V. CONCLUSION

To conclude from the results obtained, it can be seen that the vibration produced by the DC motor towards the MRE vibration isolator is decreasing with each increment in current supplied to the electromagnetic coil inside the vibration isolator. The vibration isolator that was fabricated was able to focus the magnetic flux density in the effective area of MRE. From the experimental results obtained, it can be seen that the peak value for the graphs was decreasing in value as the current applied increased. This was further proven by the RMS value calculated for the time and frequency domains where the value also decreases with each increment of current applied. This proves that MRE does have the ability to be manipulated by an external magnetic field regarding changing the stiffness and isolating vibration.

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