Simulation study of electromagnetic circuit design in laminated magnetorheological elastomer isolator

N A A Wahab¹, S A Mazlan¹, K Hairuddin¹ and H Zamzuri¹
¹Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, 54100 Jalan Semarak, Kuala Lumpur, Malaysia

E-mail: amri.kl@utm.my

Abstract. This paper presents a simulation study of magnetic flux density distribution in a laminated magnetorheological elastomer (MRE) isolator. The performance of laminated MRE isolator depends on the particular magnetic properties of materials. Therefore, the electromagnetic simulation using Finite Element Method Magnetic (FEMM) had been carried out in designing and optimizing the MRE isolator. It is apparent that the capability of magnetic flux penetrated through the MRE depends on the design parameters approach including the selection of the materials, shape of MRE, thickness of MRE and steel sheet.

1. Introduction

Magnetorheological elastomer (MRE) is a smart composite material and considered as a new generation of magnetorheological (MR) materials which composed of rubber and magnetic particles with property in such a way that the stiffness and damping are controllable with the application of magnetic field [1-4]. The innovative designs of devices that incorporate MRE for various applications such as vehicle seat vibration suspension [5, 6], and base isolation have been studied by many researchers [7-9]. Recently, the study about MRE isolator in seismic isolation system which categorized as a semi active isolation devices have been explored to reduce an earthquake vibration of civil structures [1]. Therefore, the isolation system using MRE could be considered as a potential isolator for improving seismic protection capability of structure [9, 10].

Conventionally, rubber matrix has a constant stiffness characteristic, once designed and installed to the structures, behaves as a passive type of isolation system. The development and characteristic of MRE were investigated to increase the adaptability of such passive base isolation system [8, 11, 12]. For example, Zhou et al. [8] investigated the performance comparison between an MR fluid damper and an MRE isolator in building structure. Behrooz et al. [13, 14] proposed a variable stiffness and damping isolator (VSDI) to be used in vibration mitigation of scaled building structure and the study started from the development of the MRE until the characterization of the VSDI as an isolator. Li et al. [15-17] proposed adaptive seismic isolator and tested to evaluate and characterize the behaviour of the MRE seismic isolator. However, most of the researchers focused on the development of material properties for specific applications and mechanical design of MRE isolator.

Other factors such as a design concept and an advancement of electromagnetic properties are not properly studied. Therefore, in order to predict the magnetic field strength across the MRE, an axial-symmetrical model of laminated MRE isolator was simulated using finite element method magnetics (FEMM). Furthermore, the geometrical parameters in designing the laminated MRE isolator was determined and considered to optimize the performance of the isolator.
2. Design concept of laminated MRE isolator

The conceptual design of laminated MRE isolator is based on vertical direction to absorb the vibration produced by movement of traffics. Moreover, this concept could work in horizontal direction to reduce the vibration under the seismic impact loading or shock impact from a vehicle accident. There are five main parts consisted in this design which are MRE element, steel plate, electromagnetic coil and mounting plate on the top and bottom of isolator as shown in figure 1. In order to guide the magnetic flux density across the laminated MRE isolator, some parameters have been considered during designing the device such as the shape of MRE, the materials selection for other parts of laminated MRE isolator and the type of coil. The design concept has been modified from the conventional laminated rubber bearing by adding more steel plates and an electromagnetic coil to generate magnetic field to go through the laminated MRE isolator. For increasing the magnetic flux distribution, the laminated MRE isolator is designed with 25 layers of thin MRE and 24 layers of steel sheets thickness.

The new concept of laminated MRE isolator consists of six different geometrical dimension parameters. They are the size of laminated MRE isolator, thickness of the gap between top plate and coil bobbin, thickness of the MRE and steel plate, number of layers for MRE and steel plates in the isolator, size of upper and bottom plate and size of coil bobbin. The magnetic field generated by the coils could be controlled by the current from the external direct current power source, while the shear modulus is determined by the strength of magnetic field. The shear modulus is used to determine the stiffness of the laminated MRE isolator.

3. Simulation

The electromagnetic circuit design is one of the important criteria to be considered in the proposed design of laminated MRE isolator. In this study, FEMM is used to analyse the magnetic field strength in laminated MRE isolator since it is useful for analysing the magnetic behaviour [11, 18]. In order to carry out the FEMM simulations, a two-dimensional cross section of the isolator is drawn within the FEMM, which incorporates steel plates, coils, coil cover, housing and MRE. During the initial stage, laminated MRE isolator consisted of four parts in which part 1 was the housing, part 2 was the steel plate, part 3 was the coils and part 4 was the coil cover. Part 1 and part 2 were made of magnetic material while part 4 was made of non-magnetic materials and part 3 was made of copper wire. After a few modifications, 1020 steel is used for magnetic materials, aluminium 6061-T6 for non-magnetic materials and 18 SWG coated copper wire for coil is selected to develop the laminated MRE isolator. The selection of coil in this study is selected based on the highest vanes of magnetic field intensity, \( H \). Details of each part are shown in table 1. Therefore, 18 SWG was selected with 3000 number of turns and 5 A of applied current.
For an asymptotic boundary condition, the coefficients in a boundary condition can be represented by

\[
\frac{1}{\mu_r \mu_0} \frac{\partial A}{\partial n} + c_o A + c_i = 0
\]  

Where \( A \) is magnetic vector potential, \( \mu_r \) is the relative magnetic permeability of the region adjacent to the boundary, \( \mu_0 \) is the permeability of free space, and \( n \) represents the direction normal to the boundary

\[
c_o = \frac{1}{\mu_r \mu_0 R}
\]

\[
c_i = 0
\]

Where \( R \) is the outer radius of a sphere problem domain.

4. Results and discussion
The purpose of electromagnetic circuit design in the laminated MRE isolator is to generate the highest possible magnetic flux density across the MRE. The laminated MRE isolator is modeled with asymmetric model. After the asymmetric drawing was sketched as shown in figure 2 (a), meshing area was created as shows in the figure 2 (b), the analysis results displayed the magnetic flux line as in figure 2 (c) and the flux density values in figure 2 (d).

The design parameters that considered in this model are selection of materials, diameter of coils, number of coil turns and current value that affected the magnetic field intensity \( H \), thus related to magnetic flux density \( B \) [19]. The constitutive relationship between \( B \) and \( H \) can be represented by

\[
B = \mu H
\]

Where \( B \) is the magnetic flux density, \( H \) is the field intensity, and \( \mu \) represents the material dependent parameter called permeability.

Figure 3 shows the area of MRE, which has been analyzed as the magnitude of the flux density. The average value of magnetic flux density is indicated by the effective area as shown in figure 3. The pattern of magnetic flux lines seemed to penetrate the MRE and formed a closed loop surrounding the electromagnetic coil. This is due to the presence of magnetic particles inside the MRE. The magnetic field strength is measured through various applied current from 1 A up to 5 A. Figure 4 shows magnetic flux density in the effective area based on the currents applied. According to the graph, it can be observed that the flux lines have passed across the effective region of the MRE isolator. Therefore, the MRE in the effective area can be rheologically influenced by changing of the current input. As expected, when the applied current has been increased, the magnetic flux density also increases. The average magnetic flux at the maximum current of 5 A is about 0.53T.
The result from figure 3 and 4 showed that the magnetic flux density is increased until the end of measurement points due to the magnetic concentration and permeability is higher at the end of measurement area which is the nearest to magnetic material. Therefore, the proposed laminated MRE isolator is developed with the highest possible magnetic flux density distribution through MRE in order to achieve maximum stiffness from the current value. As discussed by Li et al [3], the lateral stiffness of MRE increased when the magnetic field increased. The final geometrical dimension of the laminated MRE isolator achieved after a few modifications have been made to attain uniform magnetic field strength as shown in table 2. The size of laminated MRE isolator designed is 200 mm for width, 210 mm for length and 60 mm for thickness.
5. Conclusion
In this paper, a laminated MRE isolator was designed to be a smart device in isolation system for civil engineering application. The laminated MRE isolator was designed based on the optimization of magnetic flux density across the MRE after a several modification of magnetic material, non-magnetic material and electromagnetic circuit by using FEMM. The proposed laminated MRE isolator could generate higher magnetic field strength at MRE in the shear position of MRE. It was proven that the MRE could efficiently operate for the designed laminated MRE isolator as a seismic isolator.

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