DEVELOPMENT OF MAGNETIC CIRCUIT DESIGN IN MULTISANDWICH MAGNETO RHEOLOGICAL ELASTOMER (MRE) ISOLATOR

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Abstract- Magnetic circuit configuration for magneto rheological elastomer (MRE) isolator is one of the important criteria to produce various values of magnetic field strength. This study presents simulation exercises by taking into account the important parameters, such as cylindrical housing part, selection of materials and thickness of cylindrical housing, for obtaining the optimum magnetic field strength of multi sandwich MRE isolator. These parameters were selected based on the optimum magnetic field density at the effective areas in MRE isolator design. Finite Element Method Magnetics (FEMM) software package has been utilized to simulate magnetic field strength, generated by the electromagnetic coil for improving the MRE isolator performance. Therefore, the simulation results by incorporating the effect of cylindrical housing part, which have been added in designing the multi sandwich MRE isolator, are presented. The results showed that the average flux with magnetic cylindrical housing is increased about 64% higher than without cylindrical housing, while the range of effective thickness for cylindrical housing is from 1 to 6 mm.

Keywords- Magneto rheological Elastomer, Magnetic Circuit, Isolator

I. INTRODUCTION

Magnetorheological elastomer (MRE) is a new generation of magnetorheological (MR) family which composed of rubber and magnetic particles. The properties of MRE material corresponding to stiffness and damping, can be controlled with the application of magnetic field [1-4].MRE has attracted a great deal of attentions from researchers. The innovative designs of devices that integrated MRE for various applications such as vehicle seat vibration suspension [5-6] and base isolation [7-9]have been studied by other researchers. Recently, the study about MRE isolator in seismic isolation system which is categorized as a semi-active isolation devices has been explored in order to reduce earthquake vibration in civil structures [1-2]. Therefore, the isolation system that used MRE material has a potential in semi-active seismic isolator for improving seismic protection capability of structures[1,7,10-11].

Conventional seismic isolation system consists of rubber matrix that has a constant stiffness characteristics, once designed and installed to the structures. This properties has lead the conventional seismic isolator behaves as a passive type of isolation system [3,12]. The development and characteristics of MRE materials have been carried out to increase the adaptability of thesematerials to suppressthe passive base isolation system [8,13-14]. For example, Zhou et al. [8] investigated the performance comparison between MR fluid damper and MRE isolator in building structure. Behrooz and co-workers[15-16] had proposed a variable stiffness and damping isolator (VSDI) to be used in vibration mitigation of scaled building structure from the development of the MRE until the characterization of the VSDI as an isolator. Li et al. [12,17] proposed adaptive seismic isolator through experimental works 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 [18]. Only a little study has been done on the multi sandwich MRE isolator. Therefore, this study presents magnetic circuit design optimization using simulation software package to be used as an indicator for achieving various magnetic field strengths. An axial-symmetrical model of multisandwich MRE isolator was simulated to improve the magnetic field strength across the MRE. A few parameters such as materials selection, thickness of housing and applied currents were determined and considered to optimize the performance of the isolator.

II. DESIGN

Multi sandwich MRE isolator consists of five main parts which are multi sandwich MRE base structures, electromagnetic coil, mounting plates, coil bobbins and housing as shown in Fig. 1. The design concept has been modified from the conventional laminated rubber bearing by adding an electromagnetic coil and housing to generate and guide the magnetic field to penetrate the multi sandwich MRE isolator.

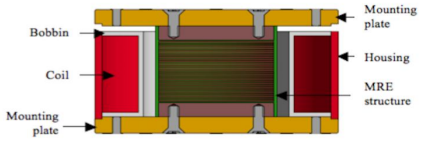


Fig.1. Conceptual design of the multisandwich MRE isolator

The multisandwich MRE base structures comprise of stiffening plate and steel blocks that immersed in the MRE compound. The structures serve as magnetic core part, which the effective stiffness or shear modulus can be altered in real time to a limited degree, in a controlled manner by varying the strength of an applied magnetic field. MRE material have low magnetic conductivity due to the large volume fraction of non-magnetic rubber matrix [17].In order to enhance magnetic conductivity in the MRE layers, the isolator was designed with 28 layers of thin MRE and 27 layers of stiffening plates with 1mm thickness. Besides, the permeability of magnetic core was improved by layering the steel block and stiffening plates with MRE compounds in the middle as depicted in Fig. 1.

Cylindrical housing was added at outside multisandwich MRE isolator and coil bobbin, where the exact type of material was yet to be considered,whethernon-magnetic and magnetic materialscategory. Another purpose of the cylindrical housing was tobe attached with the bottom mounting plate at a fixed position. Meanwhile, the electromagnetic coil was wound around bobbin to generate magnetic field. The thickness of the steel housing was also varied for obtaining the optimum magnetic field in MRE isolator.

III. MAGNETIC CIRCUIT SIMULATION

In this study, FEMM was utilized to analyse the magnetic field strength, which generated in the multisandwich MRE isolator [11,13]. A two-dimensional cross section of the isolator is drawn in the FEMM simulation. During the initial stage, this isolator was comprised of four main parts. The first part that corresponds to the top and bottom mounting plates, made of magnetic material, which has a high magnetic permeability and magnetic saturation. Meanwhile, the second part was referred to the MRE structures consist of MRE layers, steel blocks and stiffening plates. The steel blocks and stiffening plates were made of magnetic materials. The third and fourth parts were reffered to the coil bobbin (non-magnetic material) and the electromagnetic coil (copper wire), respectively. Then, the MRE isolator's design was modified with the addition of cylindrical housing that attached with the bottom mounting plate. The influence of the thickness of cylindrical housing was analysed using different types of materials,in which corresponding to the non-magnetic and magnetic materials. The purpose of this advancement was to study the distribution of magnetic flux in the multisandwich MRE isolator.

For an asymptotic boundary condition in designing the multisandwich MRE isolator, the coefficients in a boundary condition can be represented by

$$\frac{1}{\mu_r \mu_o}\frac{\partial A}{\partial n} + c_o A + c_1 = 0 \qquad (1)$$

where A is magnetic vector potential, μ_r is the relative magnetic permeability of the region adjacent to the boundary, μ_o is the permeability of free space, and n represents the direction normal to the boundary.

Coefficients C_0 and C_1 are specified by

$$c_o = \frac{1}{\mu_r \mu_o R} \qquad (2)$$

$$c_1 = 0 \qquad (3)$$

where R is the outer radius of a sphere problem domain.

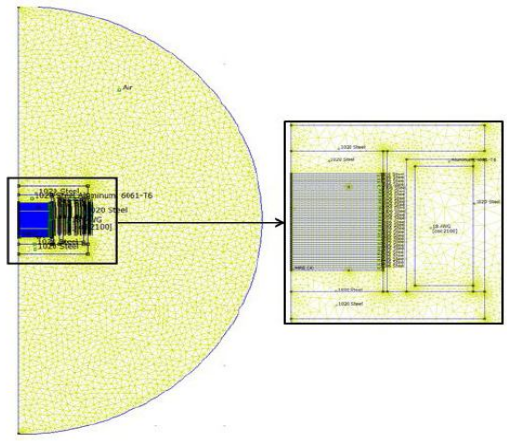


Fig.2. Meshed geometry in FEMM

After applying the boundary conditions and adding all material properties, the two-dimensional of multisandwich MRE isolator was ultimately meshed with a finer triangular mesh at the important region, which was inside the magnetic core and the coarse triangular mesh at the outside region, as shown in Fig. 2.

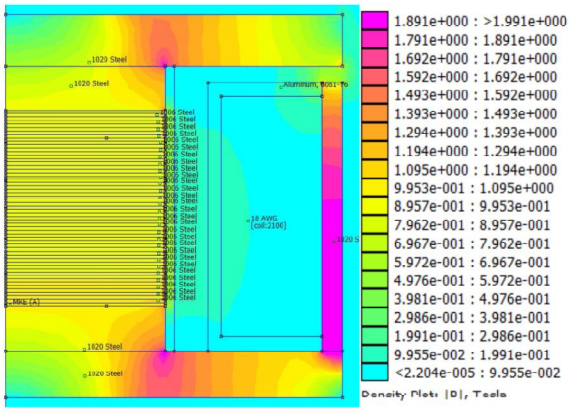


Fig.3. Simulation of magnetic flux densities in multisandwich MRE isolator

After all considerations have been designed in the FEMM software, then the multisandwich MRE isolator model was analysed. The simulated magnetic flux density distribution in the multisandwich MRE isolator is shown in Fig. 3. The magnetic properties of MRE materialhas followed the B-H curve, which

have been included in the materials library of FEMM software. MRE material containing 60% of carbonyl iron particles (CIP) was set to be used in the MRE preparation. Thus, in the FEMM software, the type of material used for each part in the isolator, type of coil, number of coil's turn around the bobbin and applied current were assigned as individually to choose the correct combination. These parameters were also crucial for obtaining the high value of the magnetic field strength in multisandwich MRE isolator.

Table 1: List of parts and materials for laminated MRE isolator

Part no	Part name	Type of material	Material	Type
1	Stiffening plate	Magnetic	Low carbon steel	1020
2	Base plate	Magnetic	Low carbon steel	1020
3	Steel block	Magnetic	Low carbon steel	1020
4	Wire coil	Non-magnetic	Copper wire	18SW G
5	Bobbin	Non-magnetic	Aluminum	6061-T6

The materials that involved in FEMM were 1020 type of mild steel for magnetic materials, aluminium 6061-T6 for non-magnetic materials and AWG 18 coil.For the number of turns for the coil was calculated based on the area of coil bobbin available, where2100 turns have been achieved. Furthermore, the selection of coil was also selected based on the highest intensity of magnetic field, *H*. Details for each part of MRE isolator are shown in Table 1. The current values were varied from 1 to 5 A. Fig. 4 shows the area of MRE, which has been analysed as the magnitude of the flux density. The average values of magnetic flux density was indicated by the effective area in the center of the thin layers at the center of MRE structure.

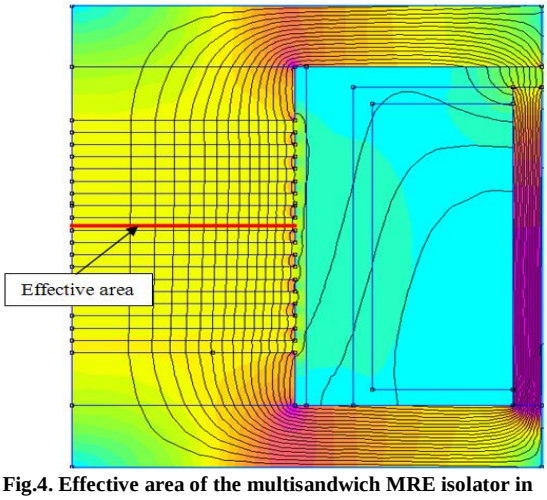


Fig.4. Effective area of the multisandwich MRE isolator in study

IV. RESULTS AND DISCUSSION

The results and discussion are based on the FEMM simulation on the multisandwich MRE isolator, after considering a few important parameters. The effect of each parameter is presented in the following sub-sections.

4.1 Effect of material selection for cylindrical housing

The selection of materials for cylindrical housing was studied to obtain the influence on the magnetic flux density in MRE. Fig. 5 shows the magnetic density plot of multisandwich MRE isolator for considering the cylindrical housing, using non-magnetic and magnetic materials for cylindrical housing. The consideration of having a cylindrical housing and materialsselection for the housing offers a high impact of the magnetic flux distribution in the isolator.In other words, the magnetic flux lines leakage was occurred when magnetic cylindrical housing was not considered in the design. This could be due to no guidance part to allow the magnetic flux to flow rather than loss to the air. The results depicted that it is essential to take into consideration the existance of housing as it guided the magnetic flux lines to distribute through MRE and prevents from high possibility of magnetic flux leakage.

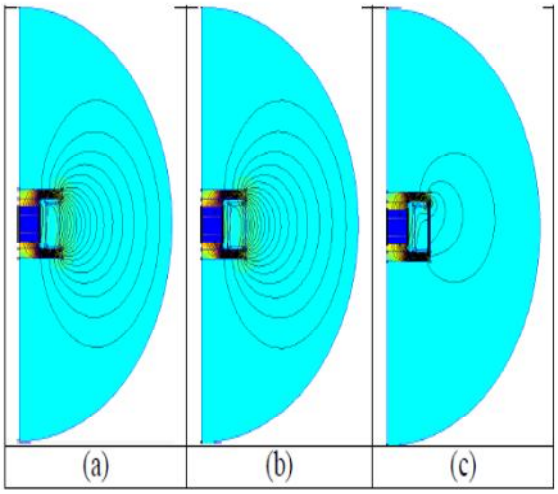


Fig.5. Density plot of multisandwich MRE isolator (a) without housing (b) with non-magnetic material's housing, and (c) with magnetic material's housing.

The result of using the magnetic cylindrical housing is shown in Fig. 6.A high magnetic flux density at nearly 0.95 T was obtained for magnetic housing, while the other two arrangements were resulted magnetic density at approximately 0.58 T. The magnetic density is concentrated at the MRE when using the magnetic housing, functions to complete the magnetic flux loops. However, without the magnetic housing, the magnetic flux tends to avoid the MRE and simultaneously reduces the magnetic flux density.

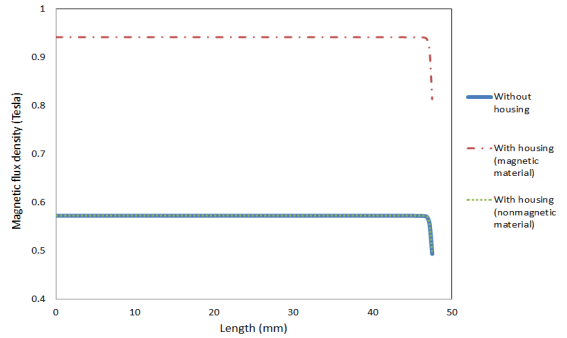


Fig.6. Magnetic flux density for different type of selection material through MRE.

The distribution of magnetic field inside the MRE was uniformed at all effective areas. This is because of the magnetic particles inside the MRE were assumed to well dispersed within MRE compound. The larger conductivity of magnetic field was obtained by using magnetic material compared to non-magnetic material for cylindrical housing since path for magnetic fluxes flow was properly guided.

4.2 Effect of variation thickness of housing

In order to study the effect of cylindrical housing thickness on the magnetic flux density that pass through the MRE, the thickness was varied from 1 to 15 mm. Fig. 7 shows the values of magnetic flux density at various thickness of cylindrical housing. The average values of magnetic flux density for 1 mm thickness of cylindrical housing is about 0.615 T. The increment of magnetic flux density for thickness 1 to 5 mm was about the same, which was at 0.13T. Started with the thickness of 7 mm and above, the increment of magnetic flux density was decreased at approximately 0.01 T. The reduction of magnetic flux density was decreased about 8%. However, due to the manufacturing limitation, it can be concluded that the effective thickness in designing the cylindrical housing was ranging from 1 to 6 mm depending on the fabrication process at a later stage.

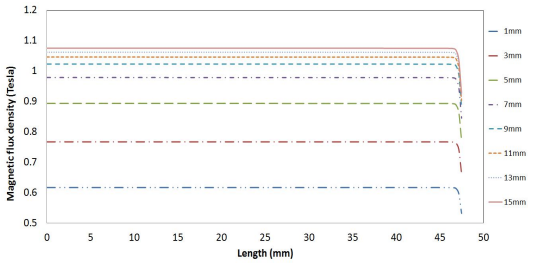


Fig.7. Magnetic flux density at various thickness of housing through MRE

4.3 Effect of variation of current to the magnetic flux performances

Applied currents are one of the controllable parameters that to be considered in designing the multisandwich MRE isolator. Fig. 8 shows the magnetic flux density under different values of applied current.As seen in the figure, the magnetic flux density increased as applied current increased. This phenomenon isin agreement with other studies done by many researchers[17-18]. The patterns of the graph are similar in such way that the flux density was constant up to approximately 46 mm and decreased drastically beyond this value. The magnetic flux density has increased from 0.22 to 0.95 T as the applied current increased from 1 to 5A. The increment, however, is not proportional with the increment of applied current. The different in values of magnetic flux density are becoming lesser as the applied current increases. Therefore, the effective areas in the MRE are affected by the applied currents, wherein general, the current play a role in determining the value of magnetic field. As expected, when the applied current increases, the magnetic flux density is also increases. The average magnetic flux at the maximum current of 5 A is about 0.94 T which was observed as the highest among all.

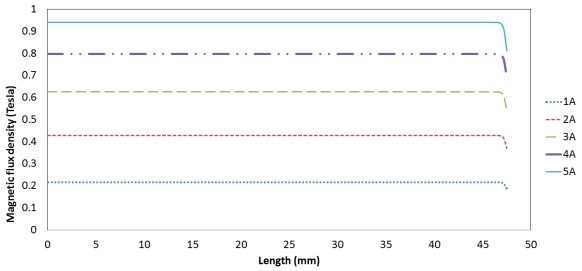


Fig.8. Magnetic flux density at various applied current through MRE

Therefore, the proposed multisandwich MRE isolator was developed with the highest possible magnetic flux density distribution through MRE in order to achieve maximum stiffness from the current value.

CONCLUSION

In this paper, a multisandwich MRE isolator was designed for isolation systemfor civil engineering applications. The design was based on the optimization of penetrated magnetic flux density across the MRE after adding cylindrical housing and effect of magnetic and non-magnetic materials by using magnetic simulation software (FEMM). The average flux was increased about 64% rather than without the cylindrical housing. It was presented that the cylindrical housing is one of important part that need to be considered in designing the multisandwich MRE isolator in order to guide and improve the magnetic flux density through multisandwich MRE structure. The thickness of cylindrical housing was varied and it can be concluded that the range of effective thickness in designing the cylindrical housing was from 1 mm to 6 mm. Futhermore, as expected, when the applied current has been increased, the magnetic flux density also increased and average values of magnetic flux at 5 A was about 0.94 T, which was the highest among all. Therefore, the proposed multisandwich MRE isolator could generate a high magnetic flux density, penetrated

through MRE. It was proven that MRE could efficiently work for the designed laminated MRE isolator as a seismic isolator.

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