Hybrid Magnetorheological Elastomer – Fluid for Vibration Isolation

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Abstract

Hybrid magnetorheological elastomer-fluid (MRE-F) isolator is a device used to bridge the limitations impose from the magnetorheological elastomer (MRE) or magnetorheological fluid (MRF) alone. MRE is known to perform better in terms of isolating vibration by stiffness changes (it's a stiffness dominant device) where as MRF is known to have problem with sedimentation of magnetizable particles due to gravity. A composite of MRE and MRF will bring the benefit of both domains into a single isolator device. Magnetorheological properties from hybrid MRE-F can be further improve by examining the various factors affecting the overall performance of the hybrid isolator.

Keywords — *Magnetorheological elastomer, magnetorheological fluid, MRE, MRE, hybrid*

I. INTRODUCTION

Vibration is a periodic motion of particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed. Although vibration is very important in delivering sound, in many cases, however, unwanted vibration exists widely in many area such as vehicles, buildings and machines that can cause mechanical malfunction, ride discomfort and noise. As for that, vibration isolator are usually installed to minimize the influence of vibration and shock to the supporting structure and surroundings, which makes them ideal for protecting instruments, equipment, machines and vehicles [1]. Consequently, developing a well performed vibration isolation system has been blooming ever since.

The vibration isolator system was first designed by taking the damping as stiffness of the most fundamental elements. The increment in the variability of the stiffness and damping can increase the capacity of the isolator to shift the resonance frequency and reduce the transmittable resonance respectively [1]. However, the low and high frequency vibrations requires different materials. The high frequency requires low stiffness and low damping mounts while the low frequency vibration requires high stiffness and high damping mounts [4]. Apparently, passive, active, and semi-active vibration isolation have been proposed that serve different performance on stiffness and damping of a system. Among them, the semi-active method is more preferable due to its stability and reliability for both low and high frequency vibrations [2,4]. Semi-active vibration isolator system mainly focusing on three different types: stiffness variable isolation system, damping variable isolation system and both stiffness and damping variable isolation system [2]. In terms of both stiffness and damping variable device, it has been fully verified that it is more effective than only damping variable or only stiffness variable isolator on vibration reduction [3,4].

II. HYBRID MAGNETORHEOLOGICAL ELASTOMER-FLUID

Present-day, due to the rise in the application demand, vibration isolator is expected to be able to serve both damping variability and stiffness variability simultaneously. Because of that, a new magnethorheological (MR) technology have been studied intensively involving MR elastomer (MRE) and MR fluid (MRF) as the front-line for MR materials. The significant character of MR materials is the continuous and reversible controllability of stiffness and damping properties under an applied magnetic field. While MRF possesses the availability to vary its damping, the MRE on the other hand can change its stiffness at the presence of magnetic field. However, the structures of the devices are based on MRF or MRE individually as the variable stiffness and damping device synergizing both the MRF and MRE to incorporate their advantages of variable damping and variable stiffness into one single compact device is rarely considered and implemented practically.

Magnetorheological Elastomers (MREs) known as magneto-sensitive elastomer are a class of smart materials whose stiffness and damping properties can be adaptively tuned at the presence of an externally applied magnetic field. MREs made up of particulate composite materials with micron sized ferrous particle dispersed in an elastic polymer matrix [5].

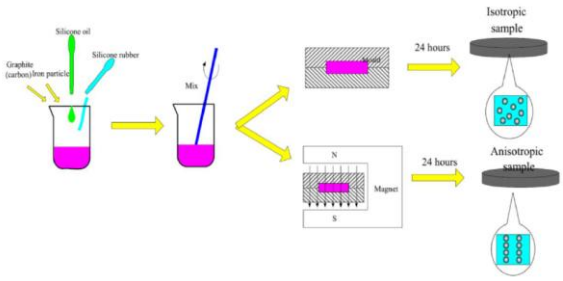

Fig. 1 MRE fabrication process

Compared to MRF, studies into the use of MRE is relatively new. Generally, the distribution of magnetic particles in the elastomer matrix divided into two types; anistropic and isotropic [7,8]. The anistropic properties is the situation where the magnetic fine particles are aligned into a specific direction and can be achieved if an external magnetic field is applied while MREs is being cured. Contrarily, in the absence of magnetic field during curing process causing the magnetic particles to be randomly distributed which is known as isotropic MRE. Both type of MREs are illustrated in Figure 1.

Before MREs, magnetorheological fluids (MRFs) were deeply studied and applied in various fields such as mechanical engineering, automotive and aerospaceas. MRFs have been found very useful in shock absorbers or dampers as the damping variability in the material properties can be controlled through an applied electromagnetic field [8-10]. MRFs are composed of magnetic particles suspended in a viscous fluid which with the influence of a magnetic field can cause changes in its physical properties [9,10]. The presence of magnetic field forces the ferromagnetic particles in the MRFs acquired magnetic dipole which then move and align themselves along the lines of magnetic flux. The changes in the material develop controllable yield strength and damping properties [9-12]. The structure and behavior of magnetorheological fluids, under no magnetic field and with applied magnetic field are presented in Figure 2

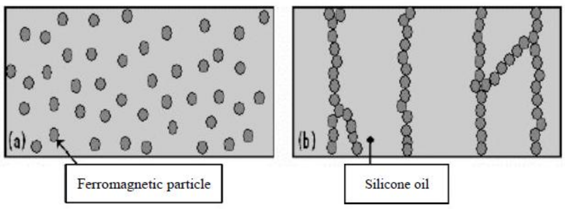

Fig. 2 Structure of magnetorheological fluids, ferromagnetic particles in a silicone oil suspension; (a) under no magnetic field, and (b) with magnetic field applied [9].

Zhiwei Xing, Miao Yu, Shuaishuai Sun, Jie Fu and Weihua Li in 2016, have investigate the development of hybrid MREF that combine a MRE stiffness unit with a MRF damping unit in parallel connection. It also evaluate the performance of the MREF experimentally by using MTS machine under multi-operating operating conditions. The field-controlled responses include stiffness variability and damping variability. Thus, a VSVD under applied magnetic field was designed as it has more advantages to decrease the resonance magnitude while maintaining the high frequency isolation performance under wide operating condition. The structural design consists two part of MRE unit and MRF unit. MRE materials was bound together and serve as the magnetic flux return that can be stretched with respect to the movement of central shaft. MRE is expected to be able to bear the static load in no power operation. Lower MRE works like a gas chamber to compensate volume change.

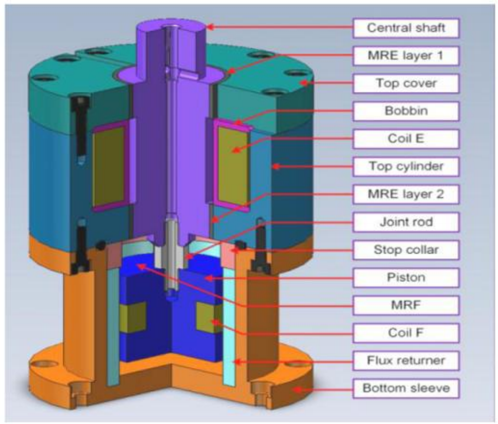

Fig. 3 Schematic of hybrid mount design [1]

The lower MRF unit consists of piston, flux returner and bottle sleeves. Both MRE and MRF units has electromagnetic coil each as the it supplied by two different channels of DC. The magnetic circuit model use Kirchoff's magnetic law and Gauss Law to analyse the magnetic field. Two component in the MREF assembly was considered separately [1]

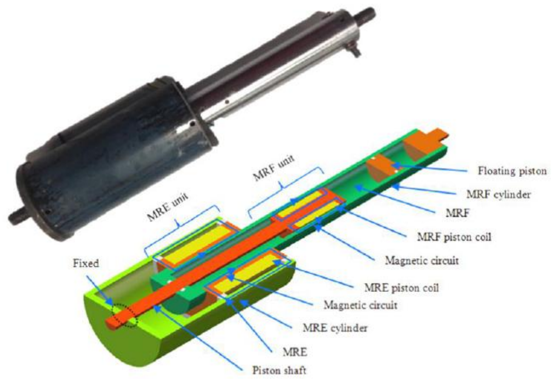

Fig. 4 Structure schematic of MRE-F isolator [2].

In the year 2017, S.S. Sun, J. Yang, W.H. Li, H. Du, G. Alici, T.H. Yan, Masami Nakano in the article; Development of an isolator working with magnetorheological elastomers and fluids reports on combination on MRF and MRE that can simultaneously controlled the damping and stiffness of the vibration which known as MRE-F. An experimental testing using the field dependant response of stiffness variability and damping variability, along with amplitude-dependant and frequency-dependant response was done separately. The design proposed contained two different part where MRF contains, piston, shaft, reservoir whereas the MRE contains annular MRE to MRF unit that uses the MRF cylinder as its piston. Both damping for MRF unit and stiffness of MRE unit is controllable depending on the magnetic density applied two different channels of direct current (DC). The design procedure is a way to determine the size of the MRF unit and MRE unit based on the required damping and stiffness force respectively. The damping of MRF is controlled by current I_1. When I_1 the magnetic circuit in MRF unit generated and the shear stress of MRF enhanced to increase the damping force. The stiffness of MRE is controlled by I_2. When I_2 the magnetic circuit in MRE unit generated and the shear stiffness of MRE enhanced to increase the stiffness. Thus, when the isolator working, the stiffness and damping can be controlled simultaneously and achieve the research objective [2].

Besides that, in the year 2011, Cristiano Spelta , Fabio Previdi , Sergio M. Savaresi , Paolo Bolzern , Maurizio Cutini , Carlo Bisaglia and Simone A. Bertinotti (2011) conducted a study on the performance analysis of semi-active suspensions with control of variable damping and stiffness. The problem considered in the study is the control design strategy of semi-active suspensions, featuring the regulation of both damping and stiffness. The study presented an evaluation of the performances and gaps achieved by such suspension in a nonlinear setting which then proposed a new comfort-oriented varable damping and stiffness control algorithm that solved the critical trade-off between the stiffness and the end-stop hitting. By comparing the passive devices and variable damping semi-active suspension, it was proven that the advantage of using a variable-damping semi-active system is uniformly better. On the other hand, by comparing the three semi-active configurations, it is proven that the lower the suspension stiffness, the better the filtering effects on the vibration. Moreover, the effect of reducing the stiffness in a semi-active suspension is larger than the effect of transforming a standard passive suspension into variable-damping suspension [3].

Ismail L. Ladipo, J.D. Fadly, and Waleed F. Faris. in the year 2015, were conducting a research on the characterization of MRE engine mount. The study was all about the simulation of magnetorheological elastomer (MREs) as engine mounts. The interest of the study was to use the MREs in a semi-active mode. Using the damping modulus and dynamic stiffness, the model is compared with passive engine mount using rubber.. For the result at the low frequency,the performance was measure using relative displacement of the engine mass and the chassis while at the high frequencies, the force transmissibility showed that MRE provides better isolation than the rubber mounts. The magnetic effects on both dynamic stiffness and damping modulus on MREs showed mere reduction in vibration. The results futher confirms that with adaptable magneto sensitive environment for MREs, futher reduction of vibration could be achieve [4].

Besides that, Ioan Bica , Eugen M. Anitas , Madalin Bunoiu , Boris Vatzulik , Iulius Juganaru were conducting an investigation on the hybrid magnetorheological elastomer: Influence of magnetic field and compression pressure on its electrical conductivity in the year 2014. The graphene nanoparticle were used to produce a hybrid electro-conductive MRE and a magnetoresistive sensor was fabricated based on the obtain hybrid MRE. The influence of the transverse magnetic field and separately of compression pressure were investigated through an experimental design testing. Based on the research, to produce a highly stable magnetorheological suspensions, graphene oxide is used because it has hydrophilic property which stick on the surface of iron particles, forming a nanometric layer. In this way, the iron particles instatenously become magnetic dipoles, forming a network of parallel chains inside hybrid MRE. As a results, the electrical conductivity of hybrid MRE were produced with the dependency between resistance, magnetic field intensity and compression pressure that can be use in various application in the engineering field [5].

In the year 2017, Ashkan Darghi in his master thesis on Fabrication, Characterization and Modeling of MREs conducted a research focusing on the static and dynamic behavior of the MREs. Six types of varying contents of rubber matrix along with the ferromagnetic particles were fabricated and characterized statically in the shear mode as a function of magnetic field intensity. Content of ferromagnetic particles were proven to have a significant influence on the magneto-mechanical properties of the MRE. Increasing the iron particles volume percentage in the elastomeric matrix magnifies notably the MR effect defined as the degree of change in the modulus of MRE in presence of the magnetic field.The dynamic responses of MREs revealed strong dependence on the strain and strain rate as well as the applied magnetic field intensity. In the results, it was shown that the proposed generalized model could accurately characterize nonlinear hysteresis properties of MRE under a wide range of loading conditions and applied magnetic fields [7].

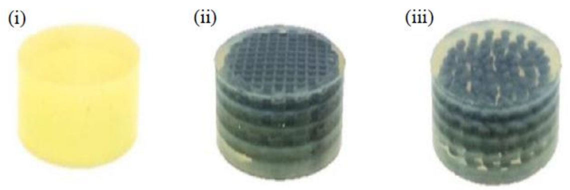

Fig. 5 Photographs of 3D printed hybrid MRE and a pure elastomer sample; (i) the pure elastomer sample; (ii) the line pattern sample; (iii) the dot pattern sample [8].

A novel hybrid magnetorheological elastomer developed by 3D printing has been studied by A.K. Bastola , V.T. Hoang and L. Li in 2016. In the study, a 3D printing technology was applied to develop a new type of hybrid MREs which combined MRFs and elastomer matrix, where highly viscous MRF filaments were configured within the elastomer matrix. Printing of the hybrid MRE is a layer-by-layer process. Each layer consistsed of a series of steps as illustrated in Figure 5. For the mechanical testing, the printed hybrid MRE samples with dot and line patterns were examined under static compression and cyclic compressive loading cycles. The results showed that the 3D printing technology is feasible for fabrication on hybrid MREs. Besides, the new hybrid MRE was able to provide a higher damping capacity and greater stiffness than conventional MREs anf MRFs. Thw dynamic stiffness and damping capacity of hybrid MREs were tunable when a moderate magnetic field strength was applied [8].

The role of MRF-E in today's world was discussed by Pawel Skalski and Klaudia Kalita in the year 2017 by presenting surveys of its applications. MRE and MRF are both belong to the smart family that can controlled the damping variability and stiffness variability in the presence of magnetic field. Due to their magnetorheological properties, MRF-E have a great potential in both present and future applications in transportation. While MRFs are widely used as damper, shock absorbers, and brakes, MREs are increasingly patented in adaptive system of energy absorption and in aviation structure. Unlike MRFs, MREs able to solve problems associates with the applications such as sealing issues, sedimentation and environmental contaminations [9].

In the year 2014, Sadak Ali Khana, A. Suresh and N. Seetha Ramaiah wrote a study on the principles, characteristics and applications of MRF damper in flow and shear mode. In this paper, the various modes of usage and characteristics are discussed. Mathematical modelingof the MR fluid dampers based on Bingham plastic model and Herschel Bulkley model are presented. .Modes of operation for MR fluid devices are utilized in flow mode, shear mode, squeeze mode and any combination of these three. Flow mode is the most widely used mode of operation in which the viscosity of the MR fluid flowing between stationary plates is changed by varying the applied magnetic field. The magnetic field dependent shear strength of MR fluid depends on several factors including the size, composition, volume fraction of the particles and the strength of the applied magnetic field. Systems that take advantage of MR fluids are potentially simpler and more reliable than conventional electromechanical devices. The design of MR fluid dampers assumes two main stages which are the hydraulic circuit design and the magnetic circuit design and commonly, the MR damper piston does not remain centered during operation. This may due to either manufacturer error or side loads due to inappropriate installation which may result in non uniform temperature increases and local overheating, bearing malfunction and leakage or scratching of the insulation and causing a short in the magnetic coil. To overcome this problem, two end collars made up of bronze are installed on either side of prototype MR damper [10].

Xiaojie Wang, Faramarz Gordanine and Gregory Hitchcock on their study on the magneto-rheological (MR) fluid-elastomer vibration isolator in 2005, have developed a MRF-E by encapsulating a MRF inside an elastomer which the structural properties of the system are controllable by an applied magnetic field. The proposed concept the magnetizable particles are encapsulated within a void in the elastomer casing and do not need alignment during the curing process. Ferrous particles inside the MR fluid-elastomer vibration isolator are mixed with a carrier fluid and have more freedom to move providing a larger damping capacity than particles embedded in a typical MR elastomer. In the study, a mechanical model was presented to investigate the dynamic behavior of the MR fluid-elastomer vibration isolators under oscillatory compressive deformations.The parameters of the model have been identified by a series of harmonic loading tests. The model comprised of a two-element system, a variable friction damping and a nonlinear spring, and the model parameters are identified from experimental data. By comparing the theoretical results to a series of experimental data, it is demonstrated that the proposed model can capture the dynamic behavior of the MR fluid-elastomer vibration isolator with the same defined parameter constants. Both the experimental and theoretical model results show that an external applied magnetic field can enhance both the damping capacity and stiffness of the MR fluid-elastomer vibration isolator [11].

III.CONCLUSION AND FUTURE WORKS

The application of magnetorheological fluid and magnetorheological elastomer with adequate controllability is important in vibration isolation problems. Magnetorheological fluid which consist of magnetizable particles in a base fluid with stabilizer additives will show behavior of semi-solid material in the presence of magnetic field. Achieving strong magnetorheological effect and reducing sedimentation of magnetizable particles due to gravity are among the two important problems require solution. Other factors deserve attentions are the shape, size, type and volume fraction of the magnetizable particles which will affect the rheological properties of the MRF.

With regards to magnetorheological elastomer (MRE), an MRE consist of polymer being mixed with magnetizable particles and its rheological properties will also changing due to presence of magnetic field. Unlike MRF, sedimentation will not become a problem in a MRE. Unfortunately, there are many research have shown that the damping property of a MRE is found be very small as compare to MRF in isolating vibration. MRE is more known as stiffness-dominant vibration isolator.

The role of hybrid magnetorheological elastomer-fluid (MRE-F) will fill the gap or limitation from MRF or MRE alone. Therefore, the progress of research in magnetorheological (MR)-based vibration isolator should be directed towards hybrid magnetorheological elastomer-fluid isolator.

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