International Journal of Engineering & Technology, 7 (4.35) (2018) 928-931

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

A Review on Hybrid Magnetorheological Isolator

Mohd Firdaus Jaafar[1*], Zarul Iqmal Mohd Razali[2], Nur Amirani Ahmad[3]

[1,2,3] *Institute of Energy Infrastructure, Universiti Tenaga Nasional, Malaysia*
**Corresponding author E-mail: mohd.firdaus@uniten.edu.my*

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*

1. Introduction

Excessive movement or vibration exists in many areas such as machines and equipment. An ordinary industrial or manufacturing workplace has a variety of machines and objects that can produce unwanted vibrations. Typical examples are motors, fans and other machines that cause abnormal vibration levels during normal use. Aside from being a burden, there are other significant effect that could result from uncontrolled vibration levels. This vibration can cause the loosening of bolts and screws, wear and tear of sensitive parts or pieces and the machine itself, production losses, degrades the efficiency of the machine or equipment and finally may harm people surrounding [1].



(a)



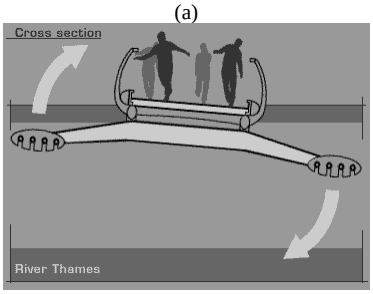
(b)

Fig. 1: Burned bearing [2] (a) and loosen screw and bolt [3] (b)

Vibration is not only limited to machine and equipment but everything that causes friction can generate vibration. Take Tacoma Narrows Bridge and Menai Suspension Bridge for example which ruined due to some random action of turbulent wind and aerodynamically poor design [4]. Of course, there were many reasons lead to the collapse, but vibration is the main cause above all. Moreover, there were quite number of 'wobbly' occurrences on bridge like Volgograd Bridge, Broughton Suspension Bridge, Millennium Bridge and Angers Bridge [4]. Ironically, these four bridges 'wobble' due to interactions between pedestrians or marching soldiers to bridge structure, causing resonance.



(a)



(b)

Fig. 2: The famous Tacoma Narrows Bridge [4] (a) and wobble phenomenon at Millennium Bridge [5] (b)

Other than vibration through wind or marching, an exercise class can cause vibration as well. TechnoMart, a skyscraper in Seoul with 39-stories shaken for about 10 minutes, eventhough no seismic activity sighted. After some investigations, the cause of 'shaken' was come from seventeen people practicing Tae Bo workout, a mixture of Taekwando and karate. The vibration caused by Tae Bo happened to collide with TechnoMart vertical vibration cycle [6]. In addition, earthquake is a form of vibration too. In fact, earthquake is the deadliest and biggest resonance. High intensity of the ground shaking may cause destruction to buildings, roads and power reactors as well as triggered tsunamis and landslides.

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.



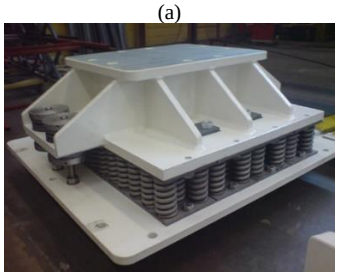
(a) (b)

Fig. 3: Belltower in Umbria, Italy before (a) and after (b) hit by 6.2 magnitude quake [7]

These catastrophic events paid a high death toll and require a lot of funding and time to bring everything back to normal. A lot of research were carried out for decades to seek out solutions to address this matter. With the effort of researchers and engineers, vibration mount is created. Vibration mounts are installed to support superstructure and to minimize the transmittable resonance to the supporting structure and surroundings [8]. Thus, makes them as the perfect protector for machines and equipments in vehicles and ships. Aircrafts like satellite or spaceship is considered as vehicle as well. The main concern here is during the launching where the vibration frequency can go up to 2000 Hz [9]. These vibration is isolated with an elastic support system to conceal the resonance and rocking. Furthermore, any civil engineering structures like bridges and buildings use seismic base isolation to mitigate the effect of great seismic occurrence. However, this technique really depends on certain range of magnitude and frequency of earthquake [10] or works better in design-level quakes [11].



(a)



(b)

Fig. 4: The base seismic isolators under the Utah State Capitol building [12] (a) and vibration mount of a machine [13] (b)

2. Active and passive isolator

Vibration mount is a type of passive isolator system. Passive here means purely use of mechanical spring or laminated rubber. It is simple, cost effective and reliable [1]. However, the system is limited to a certain limitation of damping parameter and fixed stiffness. Other example of passive isolator system is seismic base isolation which use laminated rubber bearings. Rubber and steel layers are placed on top of each other and vulcanized together. The properties of rubber cannot be changed after been vulcanized due to the passive nature of rubber. The isolation system will only withstand earthquake within the limit of that particular rubber to hold. Thus, the system will be ineffective for earthquake that below or beyond the limit [11].

Another type of isolator is active isolator system. Active is much controllable than passive system but consume power and controlled by a feedback circuit [14]. It has the ability to isolate low frequency vibration and increased its stiffness. Usually, the system has been used in a very sensitive field such as medical and measurement as precision is the main highlight. Also, active can tune the stiffness by increasing or decreasing magnetic field in the circuit. However, the system will completely inefficient when there is no power [15].

To overcome the problems of passive and active, semi-active system is introduced. Semi-active is controlled by a feedback circuit as well, thus the stiffness and damping can be varies [16]. The semi-active uses lower power consumption and less expensive components compared to active. Since the system has a passive element as well, the system will work eventhough the feedback circuit fail to function. The rubber-steel passive isolator will maintain the minimum functionality of the system [8].

Of the numerous possible technical approaches available, concepts for variable stiffness and variable damping (VSVD) based around magnetorheological (MR) material, including magnetorheological fluid (MRF) and magnetorheological elastomer (MRE) are getting popular in the vibration control system [8]. These smart materials are influenced by magnetic field. MRF is a ferrous and non-Newtonian liquid where the magnetic elements can tune or alter the rheological and damping properties when introduce to external magnetic field. However, MRF can cause few problems like precipitation of magnetic elements and leakage of the magnetic fluid [17]. MRE can handle these shortcomings. However, magnetic particles in MRE are not free to move but with MRF encapsulated, the magnetic particles are free to move [17]. In this paper, MRE and MRF isolators are focused. Different designs of Hybrid magnetorheological elastomer-fluid (MRE-F) are also reviewed. MRE and MRF can offer an integrated outcome of both and is worthy of consideration. The damping and stiffness properties were studied as well as to design a good structure that can compensate with these two MRs.

3. Hybrid magnetorheological elastomer-fluid (MRE-F)

A hybrid magnetorheological elastomer-fluid (MRE-F) is a combination of magnetorheological elastomer (MRE) and magnetorheological fluid (MRF). Wang and York teams [19, 20] have done the isolator by encapsulating a MRF in an MRE, creating more freedom for the ferrous particle to move and not required alignment during the process of curing. Before MRE or MRF been introduced in late 1990s, squeeze mode damper (SMD) with electrorheological (ER) fluid is used to control the frequency attenuations. York's team [20] has developed a mixed ER damper that handles both shear and squeeze mode. However, the ability to resist the energy decreases as the frequency increases and the fluid filled the gap affecting the dampers performance. York's team used Instron 8821S hydraulic dynamometer to test the performance on the device. The result shows the weakly dependent on frequency but strongly dependent over current.



Fig. 5: Photograph of MRF-E Composite structure prototypes. The MRF-E Composite on the left is a Poly-BD blend. The MRF-E Composite on the right is an RTV Silicon [20].

Anderson [21] has designed an isoelastic MRE-F isolator. The elastomer is in conically shaped and MRF is installed within the elastomer coated with elastomer jacket. By being equipped with both isoelastic and magnetorheological (also known as semi-active), the device is capable of providing a wide range of frequencies and the device still works passively when the magnetic field is none. Figure 7 (a) shows the isometrics of the design. Based on Figure 7 (b), the label 60, 62, 22-1, 28-1, 33, 30-1, 53-1, 50 and 56 are the top magnetic shield, bottom magnetic shield, mounting plates, MRE, MRF, elastomer jacket, electromagnet, source of magnetic field and wire leads to provide electric power.

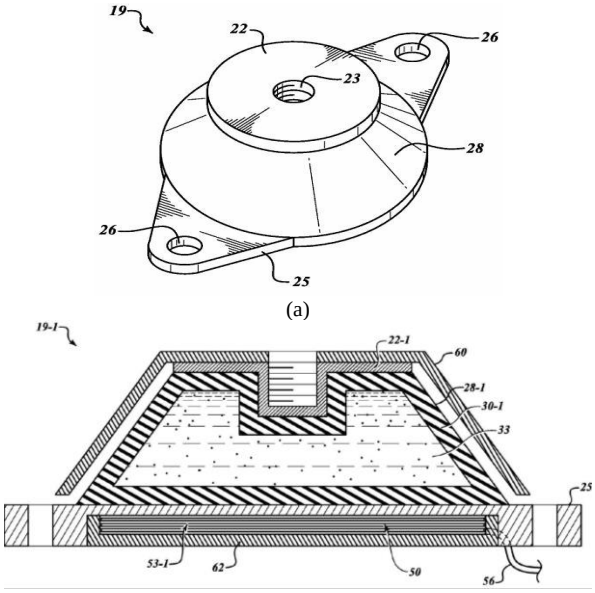


Fig. 6: Isometric view (a) and cross sectional view (b) of Anderson's design [21]

Another hybrid MRE-F based device is designed by Xing's team [8]. The difference of this design with Anderson's [21] is the usage of piston as shown in figure 8 (a). The top cover and top cylinder act as a magnetic flux return. These tops tightly bounded to hold two MREs together. MRF will be connected to an electromagnetic coil which coated with epoxy adhesive. Figure 8 (b) explains that the device will avoid any dry friction during stroking, therefore vibration from the base and dry friction will be gone. The inventors also explained the process of making the hybrid mount. For the upper mounted unit, upper MRE followed by lower MRE, joint rod and piston will be embedded with central shaft. Then, the lower damping unit filled with MRF and fastened to upper mounted unit with screws.

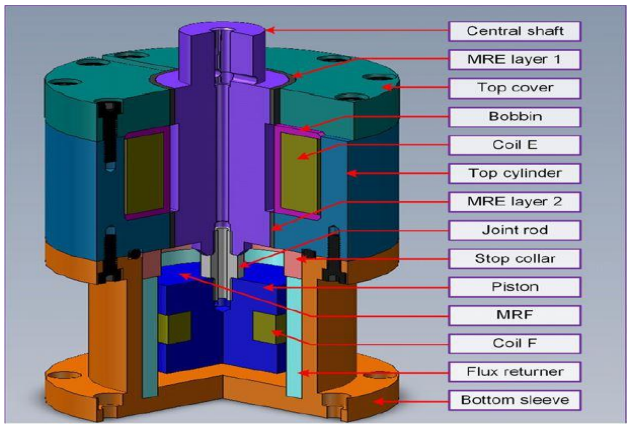


Fig. 7: Schematic of hybrid MRE-F of Xing's team invention [8]

In addition, Sun's team [1] proposed almost the same structure and working principle as Xing's team [8]. Both designs were tested using MTS machine (load Frame Model: 370.02, MTS System Corporation). Damping variability, stiffness variability, amplitude response and frequency response were to be tested. Xing's team also done a magnetic field simulation using finite element analysis (FEA) in Ansoft Maxwell software. The purpose was to determine the magnetic property of material that is suitable for the magnetic circuit design. As the result, both inventions were showing a positive result which is capable to vary the stiffness and damping by existence of current.

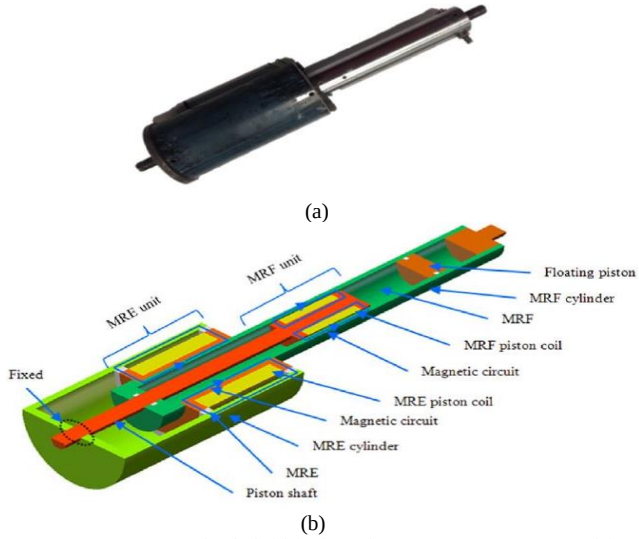


Fig. 8: A prototype of a hybrid isolator by Sun's team [1] (a) and its cross section (b)

Bastola's team has explained on the process of encapsulating MRF inside MRE [17]. In this design, MRF of 81 wt% iron particles and UV-curable silicone resin was used. The preparation of the elastomer is illustrated in Figure 10. The UV-curable silicone resin was layered into the sample vessel and cured by UV light. A void was shaped in second layer and MRF will fill up the void. The last layer of resin is dispensed on top of the MRF and cured. The sample was left for at least 24 hour to cure completely under room temperature. The change in sample's thickness was depended on the presence of magnetic field and recovered when the magnetic field was removed. In fact, in [22] also done by Bastola and he mentioned the same process.

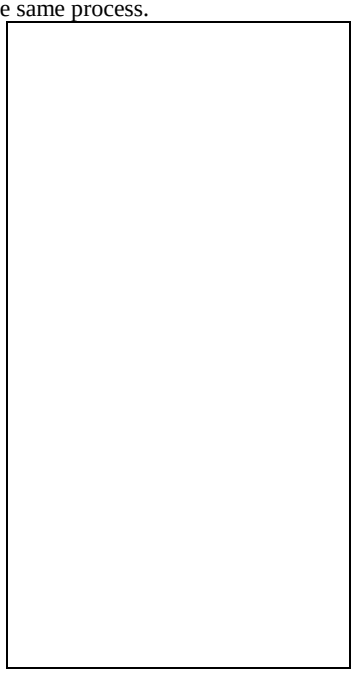


Fig. 9: Schematic illustration of the process of encapsulating the MRF into the elastomeric casing to fabricate a hybrid MRE [17].

4. Conclusion

Nowadays 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 direct towards hybrid magnetorheological elastomer-fluid isolator.

Acknowledgement

The authors would like to thank Universiti Tenaga Nasional through UNITEN Internal Grant Vote No. J510050713 for supporting this research.

References

[1] S.S.Sun, J.Yang,W.H.Li, H.Du, G.Alici, T.H.Yan and M.Nakano, "Development of an isolator working with magnetorheological elastomers and fluids," Mechanical Systems and Signal Processing, vol. 83, pp. 371-384, 2017.

[2] M.Smith, "CAUSE(S) AND CONTRIBUTING FACTORS OF EQUIPMENT AND MACHINERY FAILURE," Metropolitan Consulting Engineering & Forensics, 26 August 2015. [Online]. Available: http://metroforensics.blogspot.com/2015/08/causes-and-contributing-factors-of.html. [Accessed 3 July 2018].

[3] "Checking the Nuts and Bolts on Your Motorcycle," Cyclepedia, [Online]. Available: https://www.cyclepedia.com/nuts-and-bolt/. [Accessed 3 July 2018].

[4] "The Strangest, Most Spectacular Bridge Collapse (And How We Got It Wrong)," Motherboard, 14 December 2015. [Online]. Available: https://motherboard.vice.com/en_us/article/kb78w3/the-myth-of-galloping-gertie. [Accessed 3 July 2018].

[5] "Millennium Bridge Wobble," Nikeweekend, 26 May 2017. [Online]. Available: http://www.nikeweekend.com/millennium-bridge-wobble.html. [Accessed 3 July 2018].

[6] J.Bergen, "Korean skyscraper shakes from 17 middle-aged people doing Tae Bo," Geek, 21 July 2011. [Online]. Available: https://www.geek.com/geek-cetera/korean-skyscraper-shakes-from-17-middle-aged-people-doing-tae-bo-1405157/. [Accessed 3 July 2018].

[7] M.Palin, "Magnitude 6.2 earthquake strikes central Italy," news.com.au, 26 August 2016. [Online]. Available: https://www.news.com.au/world/europe/magnitude-62-earthquake-strikes-central-italy/news-story/a6c50a80d1300d8de1a6d2b258054ec6. [Accessed 3 July 2018].

[8] Z.Xing, M.Yu, S.Sun, J.Fu and W.Li, "A hybrid magnetorheological elastomer-fluid (MRE-F) isolation mount: development and experimental validation," Smart Materials and Structures, vol. 25, no. 1, 2016.

[9] K.Iwamoto,K.Noda,T.Suzuki,Y.Koike,H.Takahashi and M.Kato, "Semi-active vibration isolation system for launch vehicles," IFAC Proceedings Volumes, vol. 37, no. 6, pp. 991-996, 2004.

[10] Y.Li, J.Li, W.Li and B.Samali, "Development and characterization of a magnetorheological elastomer based adaptive seismic isolator," Smart Materials and Structures, vol. 23, no. 4, 2013.

[11] H.Zargar and K.L.Ryan, "Exploring the Gap Damper Concept To Control Seismic Isolation Displacement Demands," in 15WCEE, Lisboa, 2012.

[12] "Base isolation," Wikipedia, 3 June 2018. [Online]. Available: https://en.wikipedia.org/wiki/Base_isolation. [Accessed 3 July 2018].

[13] "Vibratec," Offshore Technology, [Online]. Available: https://www.offshore-technology.com/contractors/noise/vibratec/. [Accessed 4 July 2018].

[14] V.P.Mikhailov and A.M.Bazinenkov, "Active vibration isolation platform on base of magnetorheological elastomers," Journal of Magnetism and Magnetic Materials, no. 431, pp. 266-268, 2017.

[15] V.P.Mikhailov, T.L.Aung, A.A.Kopylov and D.K.Tovmachenko, "Platform for Active Vibration Isolation of the Precision Equipment Based on Magnetorheological Elastomers," in 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), Moscow, 2018.

[16] M.Behrooz, X.Wang and F.Gordaninejad, "Modelling of a new sem-active/passive magnetorheological elastomer isolator," Smart Materials and Structures, vol. 23, no. 4, 2014.

[17] A.K.Bastola, L.Li and M.Paudel, "A hybrid magnetorheological elastomer developed by encapsulation of magnetorheological fluid," Journal of Materials Science, vol. 53, no. 9, pp. 7004-7016, 2018.

[18] J.N.Ghojogh, "Application of Smart Technologies in Drilling Fluids," ResearchGate, 26 July 2016.

[19] X.Wang, F.Gordaninejad and G.Hitchcock, "A magneto-rheological fluid-elastomer vibration isolation," Smart Structures and Materials, vol. 5760, pp. 217-225, 2005.

[20] D.York, X.Wang and F.Gordaninejad, "A New MR Fluid-ELastomer Vibration Isolator," Journal of Intelligent Material Systems and Structures, vol. 18, no. 12, pp. 1221-1225, 2007.

[21] R. B. Anderson, "Isoelastic Magneto-rheological elastomer isolator". United Stated of America Patent 8152145 B2, 10 April 2012.

[22] A.K.Bastola, V.T.Hoang and L.Li, "A novel hybrid magnetorheological elastomer developed by 3D printing," Materials and Design, vol. 114, pp. 391-397, 2017.