Design and Numerical Analysis of a Magnetorheological (MR) Damper

S M Farhan Rakib
Department of Electrical and Electronics Engineering
International Islamic University Chittagong
Chattogram 4318, Bangladesh

Md. Mofij Uddin
Department of Electrical and Electronics Engineering
International Islamic University Chittagong
Chattogram 4318, Bangladesh

Kazi Rabiul Alam
Department of Electrical and Electronics Engineering
International Islamic University Chittagong
Chattogram 4318, Bangladesh

Md. Faisal Hossen Bablo
Department of Electrical and Electronics Engineering
International Islamic University Chittagong
Chattogram 4318, Bangladesh

Farhadul Islam
Department of Electrical and Electronics Engineering
Chittagong University of Engineering and Technology
Chattogram 4349, Bangladesh

Md. Bourhan Uddin
Department of Electrical and Electronic Engineering
International Islamic University Chittagong
Chattogram 4318, Bangladesh

Arif Mahmud Majumder
Department of Electrical and Electronics Engineering
International Islamic University Chittagong
Chattogram 4318, Bangladesh

Abstract:- For a damper design in 2D axisymmetric plot, Ansys Apdl 2020 R2 software has been used. Ansys Apdl software has been chosen over MATLAB Simulink for designing damper in 3D shape. For the MR damper design B-H curve MR fluid 132 DG had been required. For the designing process of the damper firstly software learnings have been done. Ansys Apdl is the best software for determining FEM analysis. Beginning of the process of designing, different kinds of relative permeability for the MR damper parts has been collected. Basically, there are five different kinds of parts contains in an ideal MR damper. In the entire research vibration control for semi-active devices was first concern. Again, application of MR damper studied with proper arrangement. After defining the area of the MR damper, the plot data from 2D axisymmetric plot for damper design has been put. During the damper design its strongly kept in mind to design the damper more efficient and vibration controllable for any kind of vehicle. A brief study on coil wire gauge has been performed and implemented higher value of wire gauge to make the design. Accordingly, meshing of the MR damper has been done to see the current flow and boundary condition. The solution result for magnetic flux density and magnetic field intensity has been kept for current value 0.1 to 1.5 to analysis those with the shear stress. Vector diagram and 2-D flux line had simulated for having better analysis data and also for understanding the behavior of MR fluid region. Application and limitations on MR damper have been investigated through the entire process of the writings of this research and also a logical comparison with shear stress vs magnetic flux density and intensity has been shown.

Keywords:- *MR Damper, B-H Curve, Ansys Apdl 2020 R2, Shear Stress.*

I. INTRODUCTION

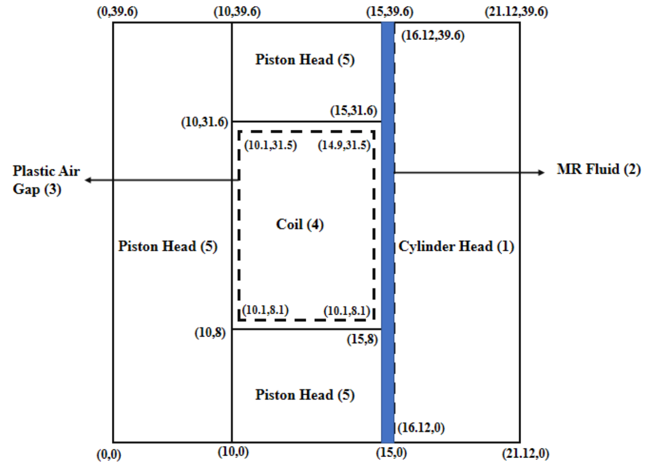
MR damper is an interest of research for the modern time. It plays a vital role in the economy of semi active devices. In near future MR damper will be available to control the vibration of semi-active vehicle more effectively than today [1]. It will also be available to control the vibration of bridges. MR damper basically capable of controlling vibration of any matter. It could be semi -active devices from vibration, buildings from earthquakes etc. For the upcoming generation the wants of MR damper is beggar description. MR fluid is a great invention of modern science and technology. MR Damper technology has been using for a long time to improve the semi-active devices [2]. MR damper has been used in many cars to control the vibration. To control the vibration of the semi- active device’s MR damper plays a significant role. For the higher efficiency MR damper is far ahead than any other conventional damper [3]. The basic construction of an MR fluid damper is the suspension of ferromagnetic particles into ferromagnetic particles. Any carrier fluid with particles containing mostly carbon particles, as they are relatively inexpensive, for procurement [4].

II. FINITE ELEMENT ANALYSIS

2D flux line of a MR damper shows where to where electron is flowing and where the electron exists. 2D flux showing different values in the right side. From different studies it is known that 2D flux line A can be equals to the 2D

ISSN No:-2456-2165

area E and A. 2D flux line. Dot of two products represents the products of their magnitude [5].



(a)

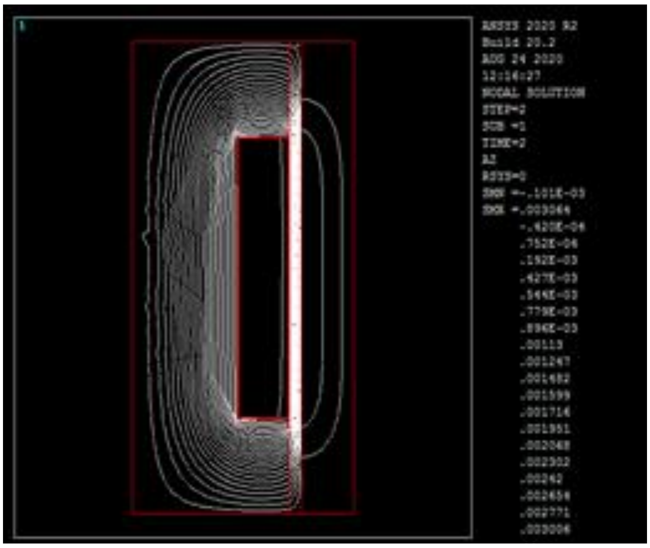
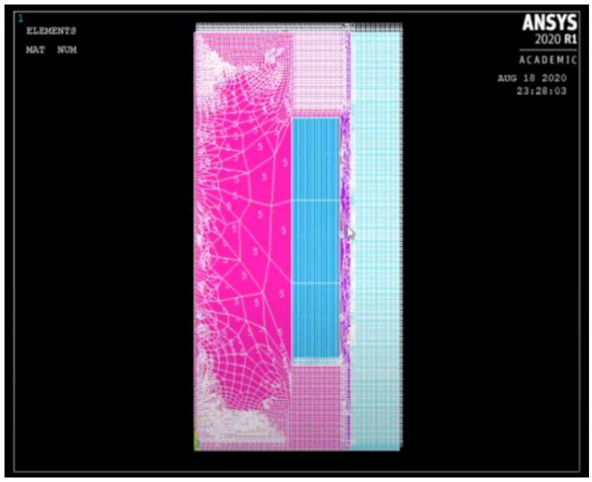


Fig. 1. (a) 2D Axisymmetric Plot of MR Damper (b) 2D flux line

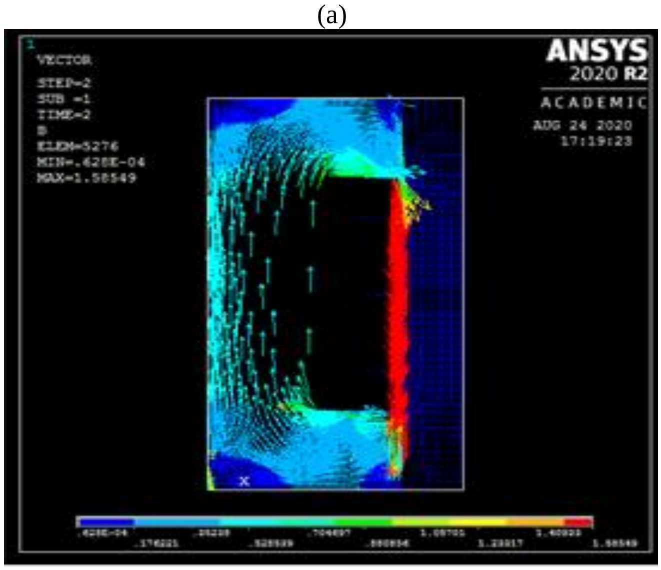
In Fig 1(a): Area 01: Cylinder (Relative Permeability= 1) Area 02: MR Fluid (Relative Permeability= B-H Curve) Area 03: Air Gap(Plastic) (Relative Permeability= 0.005) Area 04: Coil (Relative Permeability= 1) Area 05: Piston (Relative Permeability= 1137) Current Density, Js=NI/A (where, A= Area of Electrical Coil, N= Number of Turns, I= Current) a current density of Js=2711864.4 A/m² for N=800 turns, I=0.4A and Area=118x10-6 m² is used.

Vector diagram has been observed as predefined values. Its shows the vector line for electrical coil area. From the figure it is clear that the vector line is moving slightly right side upper from the lower portion [6]. The moving vector particles has its own value & position. From the process given bellow the vector diagram of MR damper:

Main Menu > General Postprocessor > Plot Results >Flux Pearl > Vector Diagram. Vector Diagram represents where the MR fluid are moving in the surface area of the designed MR damper. In Fig. 2 there is showing vector lines clearly which is continuously moving upwards. Unlike 2D flux the process to see the vector diagram is Main Menu > General Postprocessor > Plot Results >Flux Pearl > Vector Diagram. Vector Diagram represents the flow rate and direction of the MR fluid in presence of magnetic field.



(a)



(b)

Fig. 2. (a) Mesh Analysis (b)Vector Diagram

The result found for the magnetic field intensity sum which is known as HSUM. To get the value of Magnetic flux density vector sum, it has been taken average the value of minimum and maximum value of BSUM which can be described by below equation [7].

$$Havg = \frac{Hmax+Hmin}{2} \qquad (1)$$

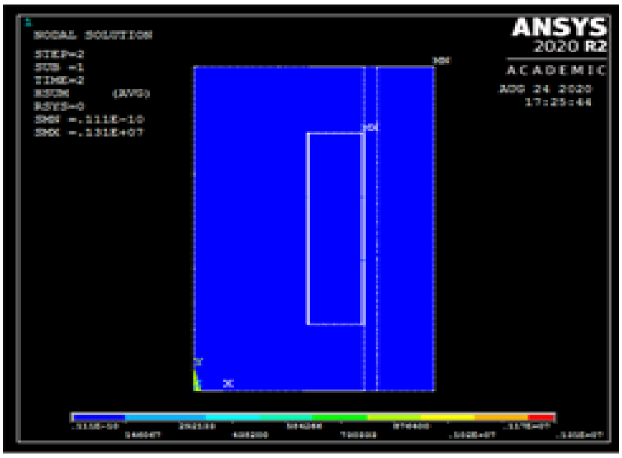
For having the magnetic flux density there is an equation which consists current, number of turns produced by the coil,

$$JS = \frac{NI}{A} \qquad (2)$$

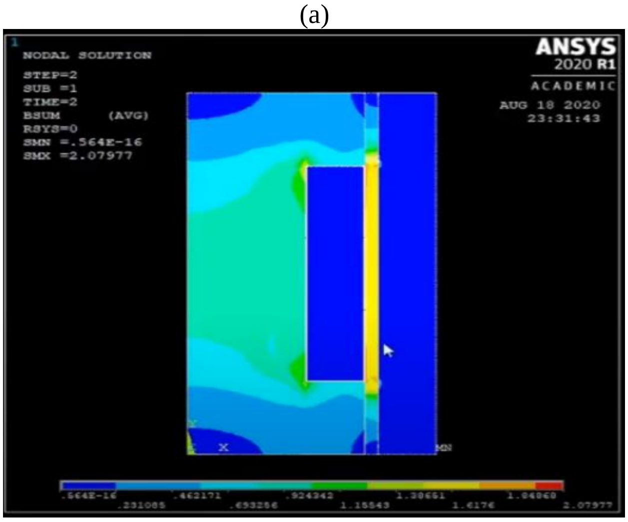
Here N= Number of turns produced by coil
I= Current
A= Area of the coil

Magnetic field intensity captures the fluid boundary in a MR coil region. Magnetic field intensity is the area where force applied by the north unit pole. Magnetic field intensity unit is A/m. [8].

Magnetic field intensity is necessary to calculate in the MR damper as with the increasing of magnetic field intensity the value of shear stress also increases.



(a)



(b)

Fig. 3. Magnetic field intensity

For the magnetic flux density, the same path has been followed in the result section.

Main Menu > General Postprocessor > Plot Results >Flux Pearl > Magnetic flux density

$$BSUM_{avg} = \frac{BSUMmin + BSUMmax}{2} \quad (3)$$

Fig. 4 shows the 3D design of MR damper. 3D design of MR damper is much more necessary to understand the shape of MR damper. There had been used five materials to design the Damper which is clearly showing in the 3D view of the damper.

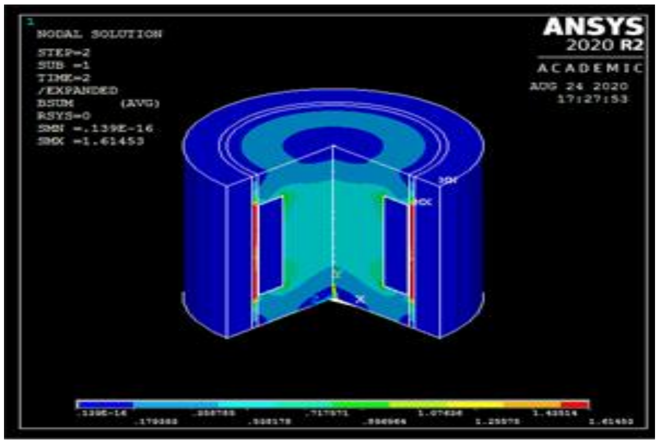


Fig. 4. 3D design of MR damper

III. RESULTS

Magnetic flux density vs current showing in Fig 5 which is a linear line. For the increasing value of flux density current also increases. when current is 0.1 then the magnetic flux density is 0.8. Again, when current is 1.6 A flux density also 1.6 A.

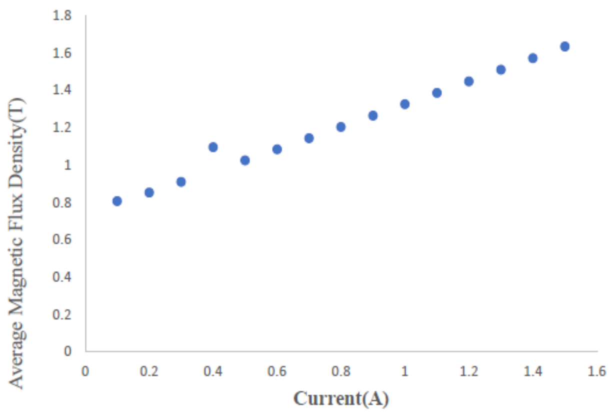


Fig. 5. Magnetic flux density vs current

In Fig 6 shown, the magnetic flux density for the lowest magnetic flux density is 0.6 it it's clearly affected the shear stress with 33 and for the increasing number of magnetic flux density to 1 shear stress also increasing. From 1 to 1.5 shear stress is dropping below accordingly. Again, proceeding from 1.5 to further shear stress is gaining again.

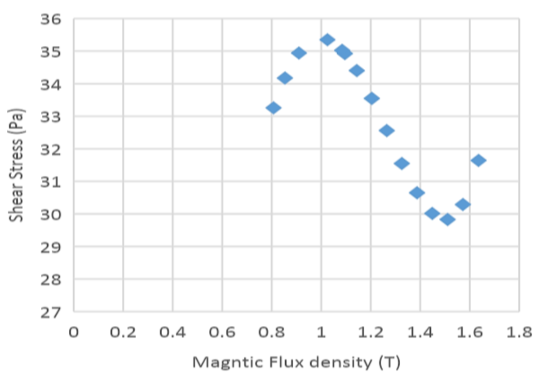


Fig. 6. Shear stress vs magnetic flux density

Shear stress vs magnetic flux density also act proportionally. With the increasing value of shear stress, the value of magnetic flux density increases. Again, for the Fig. 7 with the shear stress the value of current also increases.

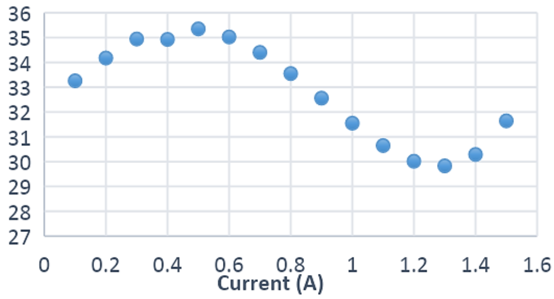


Fig. 7. Shear stress vs current

Unlike first data, it is noticing that for the increasing number of magnetic field intensity shear stress is also increasing. Shear stress is 0 when magnetic flux density is at 500000. again, shear stress at best high when magnetic flux density is at 10000000, shown in Fig 8. so, it can learn from the graph that shear stress does increase with the increasing number of magnetic flux density.

Table 1. Magnetic flux density and shear stress

Current (A)	Average Magnetic flux density	Shear stress(pa)
0.1	0.807265	33.25835
0.2	0.85337	34.1754
0.3	0.90993	34.94334
0.4	1.095735	34.92643
0.5	1.025165	35.35067
0.6	1.08438	35.02438
0.7	1.14396	34.40196
0.8	1.02425	33.54893
0.9	1.264955	32.55906
1	1.325855	31.54855
1.1	1.387155	30.64795
1.2	1.448795	30.01475
1.3	1.510605	29.82878
1.4	1.5726	30.2882
1.5	1.63569	31.64325

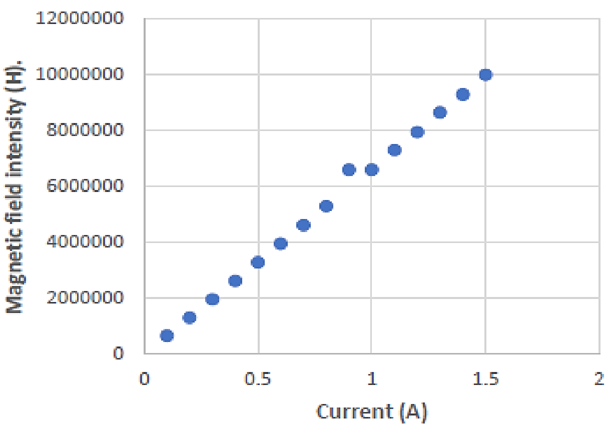


Fig 8: Current (A) versus Magnetic Field Intensity (H).

With the increasing of current it has been witnessed that the magnetic field intensity can be boost. As a result, the vibration in semi- active devices can be controlled. From the figure it shows that the figure constructed a straight line for the increasing value of current. For the increasing value of current to 1.5 the magnetic flux density is 10000000. The straight line changes a little bit higher for 0.9. For the increasing number of current value shear stress also increasing. For the current value 1.5 shear stress is at its highest which is between 6E+29 to 5E+29. In Fig 9 demonstrated that shear stress increases exponentially with the increasing number of current.

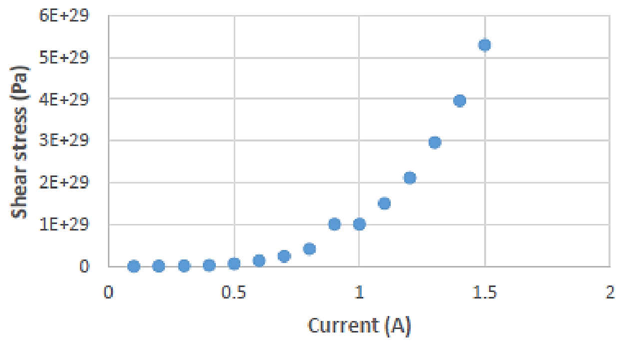


Fig. 9: Current (A) versus shear stress (Pa).

Table 1 is showing the value of minimum magnetic flux density and maximum magnetic flux density which has been simulated from finite element analysis. For the current value of 0.1A to 1.5A there is the average magnetic flux density and shear stress.

$$\tau = 52.962 * B^4 - 176.51 * B^3 + 158.79 * B^2 + 0.144$$

IV. COMPARISON WITH PREVIOUS WORK

For different current values of the magnetic flux density T is showing in the table 2 which clearly shows the difference between previous work and this work. For about 15^{th} number of models designed for current value 0.1 the magnetic flux density is 0.2527. on the contrary in Ansys Apdl 2020 R2 software the value is 1.61453 which is clearly ahead.

Table 2. Comparison

Currents A	Magnetic flux density T (own data)	Magnetic flux density T (Normal Damper)
0.1	1.61453	0.2527
0.2	1.70674	0.3176
0.3	1.81986	0.4610
0.4	2.19147	0.5909
0.5	2.05033	0.6801
0.6	2.16876	0.7380
0.7	2.28792	0.7951
0.8	2.4085	0.8493
0.9	2.52991	0.9027
1	2.65171	0.9259
1.1	2.77431	null
1.2	2.89759	null
1.3	3.02121	null
1.4	3.1452	null
1.5	3.27138	null

ISSN No:-2456-2165

V. CONCLUSION

In the entire research application of MR damper has been learnt. Vibration control of MR damper is a basic problem for semi-active devices. The way in this research shown graphical relation between magnetic flux density and shear stress, vibration control is very much possible to meet the needs for automobiles. Through the entire research further application of MR damper rather than semi-active devices has been investigated. With the continuation of magnetic flux density vs shear stress, a comparison of magnetic field intensity with shear stress logically explained. In this research a magnetorheological damper has been designed which has better magnetic flux density and magnetic field intensity than another damper. Better slopes for magnetic flux density vs shear stress, current vs shear stress, magnetic field intensity vs shear stress has been found in this research which designed damper is quite different from another damper as the wire gauge of the deigned damper has been increases 10 times bigger for having better torque and efficiency. In the designed damper the used materials compatibility was accurate than other conventional dampers. Future vibration control experiment will be possible by this.

REFERENCES

[1]. J. C. Poynor, C. Reinholtz, and H. Robertshaw, “Innovative Designs for Magneto-Rheological Dampers,” Virginia Tech, Aug. 2001. Accessed: Dec. 12, 2020.

[2]. J. D. Carlson, D. M. Catanzarite, and K. A. S. Clair, “Commercial magneto-rheological fluid devices,” Int. J. Mod. Phys. B, vol. 10, no. 23–24, pp. 2857–2865, Oct. 1996, doi: 10.1142/s0217979296001306.

[3]. O. Ashour, C. A. Rogers, and W. Kordonsky, “Magnetorheological Fluids: Materials, Characterization, and Devices,” J. Intell. Mater. Syst. Struct., vol. 7, no. 2, pp. 123–130, Mar. 1996, doi: 10.1177/1045389X9600700201.

[4]. “Race Car Vehicle Dynamics.” https://www.sae.org/publications/books/content/r-146/ (accessed Dec. 12, 2020).

[5]. Y. Rong, R. Tao, and X. Tang, “Flexible fixturing with phase-change materials. Part 1. Experimental study on magnetorheological fluids,” *Int. J. Adv. Manuf. Technol.*, vol. 16, no. 11, pp. 822–829, 2000, doi: 10.1007/s001700070016.

[6]. U. Dassanayake, S. Fraden, and A. Van Blaaderen, “Structure of electrorheological fluids,” *J. Chem. Phys.*, vol. 112, no. 8, pp. 3851–3858, Feb. 2000, doi: 10.1063/1.480933.

[7]. M. R. Jolly, J. W. Bender, and J. D. Carlson, “<title>Properties and applications of commercial magnetorheological fluids</title>.

[8]. Xu, Zhao-Dong, Ling-Feng Sha, Xiang-Cheng Zhang, and Han-Hu Ye. "Design, performance test and analysis on magnetorheological damper for earthquake mitigation." *Structural Control and Health Monitoring* 20, no. 6 (2013): 956-970.

[9]. M Mao, Min, Wei Hu, Young-Tai Choi, and Norman M. Wereley. "A magnetorheological damper with bifold valves for shock and vibration mitigation." Journal of Intelligent Material Systems and Structures 18, no. 12 (2007): 1227-1232.

[10]. Yazid, Izyan Iryani Mohd, Saiful Amri Mazlan, Takehito Kikuchi, Hairi Zamzuri, and Fitrian Imaduddin. "Design of magnetorheological damper with a combination of shear and squeeze modes." *Materials & Design (1980-2015)* 54 (2014): 87-95.

[11]. Tusset, Angelo Marcelo, Marat Rafikov, and José Manoel Balthazar. "An intelligent controller design for magnetorheological damper based on a quarter-car model." *Journal of Vibration and Control* 15, no. 12 (2009): 1907-1920.

[12]. Pour, Davood Sajedi, and Saeed Behbahani. "Semi-active fuzzy control of machine tool chatter vibration using smart MR dampers." *The International Journal of Advanced Manufacturing Technology* 83, no. 1-4 (2016): 421-428.

[13]. Sohn, Jung Woo, Jong-Seok Oh, and Seung-Bok Choi. "Design and novel type of a magnetorheological damper featuring piston bypass hole." *Smart Materials and Structures* 24, no. 3 (2015): 035013.

[14]. Kim, Yeesock, Reza Langari, and Stefan Hurlebaus. "Semiactive nonlinear control of a building with a magnetorheological damper system." *Mechanical systems and signal processing* 23, no. 2 (2009): 300-315.

[15]. Chooi, Weng W., and S. Olutunde Oyadiji. "Design, modelling and testing of magnetorheological (MR) dampers using analytical flow solutions." *Computers & structures* 86, no. 3-5 (2008): 473-482.

[16]. Liao, C. R., D. X. Zhao, L. Xie, and Q. Liu. "A design methodology for a magnetorheological fluid damper based on a multi-stage radial flow mode." *Smart materials and structures* 21, no. 8 (2012): 085005.

[17]. Schurter, Kyle C., and Paul N. Roschke. "Fuzzy modeling of a magnetorheological damper using ANFIS." In *Ninth IEEE International Conference on Fuzzy Systems. FUZZ-IEEE 2000 (Cat. No. 00CH37063)*, vol. 1, pp. 122-127. IEEE, 200