A Literature review of MR Damper - Design and Analysis

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Abstract: *A literature review is done on MR. Damper to understand the working and requirement of development, with the help of its design, analysis, and its applications. Recently many of the work is get conducted to improve the damping technology and to decrease the vibration. Magnetorheological fluid is used for control high intensity vibration. MR system can be controlled under different conditions. Important properties of MR damper are density of fluid, magnetic field strength, coil winding rheological properties.MR Damper produces large damping force by applying low voltage. The MR damper contains electromagnet to produce sufficient amount of magnetic field required for working of MR fluid. This paper contains a review about Design, analysis, M.R. Fluid ,new technology, performance under different conditions and its applications.*

Keywords: Magnetorheological fluid, Magnetorheological damper, Coil winding, Magnetic field.

1. Introduction

Nowadays the suspension of automobile or structural building is necessary to provide comfort to human beings. Magnetorheological damper (MR damper)are used for different applications. There is huge scope to work in MR damper because it reduces dynamic and static vibration forces developed in machine or structure elements to increase their efficiency and life. The MR damper is semi- active device in which by using input electric current the viscosity of fluid is regulated and hence damping performance is changed. Due to inherent non-linear as well as hysteretic dynamics it is not tough task to model the dynamic of MR damper. Based on road situation and vehicle operation the widely use of hydraulic mount is less capable of real time performance. MR damper is the most intelligent damper for providing cushioning to user by absorbing damping force. It also provides less damage to the structural building during earthquake situation. MR damper having so much advantages that it takes less energy consumption, provides quick response to damping forces, wide dynamic range and good controllable over the system. MR damper contains some important part to study and design to increase performance of MR damper. MR Fluid divides in two parts. First part contains liquid and other part contains iron particles. Performance of damper may be affected by using various compositions of liquid to increase viscosity and life of damper, by varying iron particles size which affects the performance of damping force. The working of MR Fluid when eddy current is provided then fluid particles becoming aligned with the field and increase the viscosity of fluid as shown in figure 1.1

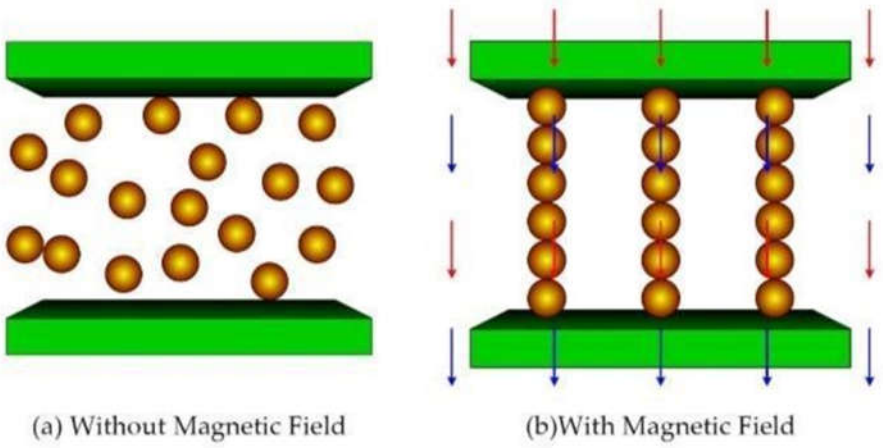

Figure 1.1 Working Principle of MR fluid [1]

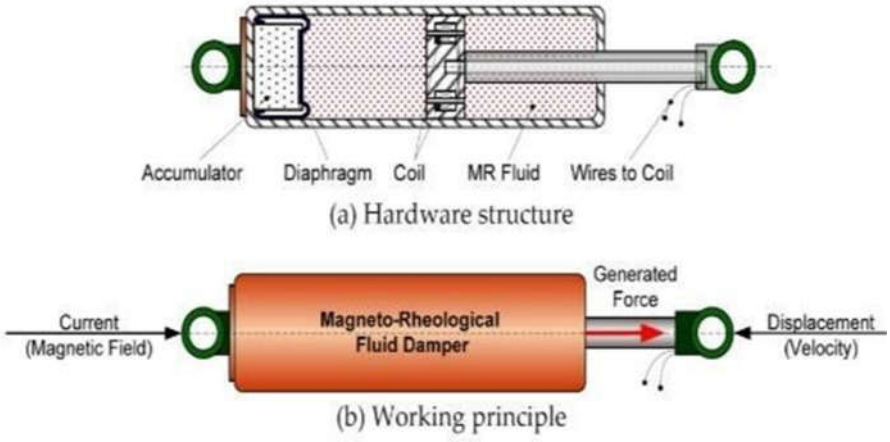

Figure 1.2 MR Damper [1]

As compared with active suspension passive suspension decrease the performance of suspension system. The general working of MR damper is shown in Figure 1.2.In this paper we are discussing the design, fluid, vibration forces of MR damper in the literature review and conclusion of this paper is in conclusion section.

2. Literature review

2.1. Work related to Design

H.Sachin et al.[2],have performed particular Magnetorheological fluid bypass damper has been designed for a heavy vehicle controllable suspension system. Also it has been fabricated and tested. For that by using vehicle commercial software and by integrating the simulink control programme, the dynamic simulation of the rollover performance of a heavy vehicle incorporated with controlled full scale MRF damper have been done. The motto of this all work is to develop full scale MRF dampers for suspension systems of heavy vehicles. Here the two controlled methods have been used. This is 'Controlled-MRF4' & 'Controlled MRF2'. These two methods have been examined and compared to uncontrolled MRF dampers & OEM dampers. After that we know the capability of MRF dampers is higher to prevent rollover during the emergency lane change than uncontrolled & OEM dampers. This

all study explains the handling benefits and potential safety of MRF damper technology application for commercial vehicles.

Jorge Lozoya et al. [3] has given that by using faulty damper can cause car off balancing. It has been shown that due to fault in MR damper give loss of oil volume. Based on the deflection of the suspension the component of fault detection system the frequency estimator bis used. The switch has been used to sense transmissibility domain to improve efficiency. Conclusion of this paper is to improved version of monitoring a MR damper condition. It gives earlier results for transmissibility of good indicator for faulty MR damper.

A.J.D. Nanthakumar et al. [4] ,In his research paper the design and analysis of MR fluid damper for vibration control has been carried out. A MR fluid damper is a potential tool in vibration control. Here by considering the domain as an axisymmetric model the analysis has carried out. It explains that the damping force of a damper depends on induced shear stress, yield stress and fluid viscosity, due to magnetic flux applied. Also this damping force depends upon dimensions of component like dimension of piston, annular orifice, rheological behaviour of damper fluid, no. of turns of electromagnetic coil and the current magnitude flowing through coil. This research work describes the flux magnitude due to current flow in the coil. The yield stress increases due to magnetic flux change. Also this paper explains the dimension of magnetic circuits.

Choi, Y.T et al.[5],This article deals with development of the design analysis and control of adaptive MR landing gear dampers. For a helicopter to achieve a desired stroking load of 17.8KN over a desired equivalent sink range 6-12 ft/s this damper has designed. The motive of this study is to improve the performance of light weight helicopter skid landing gear systems. Here with the help of a servo hydraulic testing machine the damper force is measured. The stroking load is successfully regulated using a force feedback controller.

Wentao Li et al. [6],This paper presents mechanical model of several MR fluid damper. Firstly Bingham Visco-plastic model and its characteristics have discussed. This model is the simple and most commonly used model for predicting the response of MR damping system. It is simple and easy to understand and analyse. But it can't describe the damping force velocity, non linearity and it is not applicable to control analysis. Bingham visco-elastic model overcomes the drawback of previous Bingham's model, which can reflect the hysteresis characteristics of magnetoreological fluid. The force displacement relationship of MR Damper can be described effectively by this model. Bouc Wen model has smooth transition curve, easy to carry on the numerical calculation, the versatility is strong and can reflect all kinds of hysteresis curve and has been widely used in modelling of hysteretic system.

A. Ashfak, et al.[7] have designed MR Damper, fabrication and evaluation of its performance is carried out. It also gives brief description about type of MR Damper. For designing Damper mathematical modeling is done by Bingham equations. Testing of fabricated damper is carried out on dynamic testing machine. Frequency 2Hz with strock length 20 mm and voltage between 0 to 4v across coil provided. The testing and analysis of model shows that the damping force is very low for zero current and it increases gradually as current get increased. Also yield stress part is dominated by viscous force. It shows it is necessary to have a good control over damping force for semi active control.

S. K. Mangal et al. [8], have prepared a two axis model based on finite element method concept is developed on the ANSYS software to analysis and find out the characteristics of MR damper. Based on the finite element model, a prototype of the MR damper is manufactured and test experimentally in the semi active vibration lab. The comparison between two model analysis gives the FEM model is effectively represent the experimental behavior of the MR damper in the form of damping force. From various graphical result it is observed that total maximum damping force experienced by the damper is around 500 N which occurs at 0.7 A. The result of this work is helpful to produce the damper which is more

efficient and safe MR dampers and also to find out its damping force characteristics.The analysis performed in this paper is by enough for the control and design of a MR damper.

G.Z.Yao et al. [9] have worked on a semiactive control of vehicle suspension system with magnetorheological damper is studied. At first a MR damper working in flow mode is designed. Before going for actual testing a small pre-test is done for this damper on INSTRON machine. Then a mathematical model, bouc-wen model, is adopted to describe the performance of the MR damper. With the help of METLAB software's optimization method the experimental results of MR damper was obtained. Then the car model is prepared which contains the model of the MR damper and the semi-active control strategy is used to control the vibration of suspension. At the end simulation gives the result that the semi-active control system is provide good control over suspension.

2.2. Work related to Fluid

Mukai Wang et al. [10] have discussed about MR damper with a bi fold valve implemented as an inner bypass has been used and fabricated. A theoretical model using FEMA is developed and characteristics are experimentally calculated. A MR damper with annular valve introduced within the piston subjected to the make sure it can occupied the identical external volume as that of MRBV damper, is additionally analyzed to improved performance of the MR damper. The comparison is completed between two dampers on basis of field-off damping force, field on damping force, equivalent damping and dynamic range. The results give that the MRBV damper can provide lower field-off damping force with larger field-on damping force than the MRAV damper. In order to search out out the benefits of the vibration performance of the MRBV damper, only 1 degree of freedom isolation system supported the 2 MR dampers is evaluated.

Zekeriya Parlak et al[11], in this paper, design optimization method has been allotted to attain damper force and maximum magnetic denseness of an MR damper has been presented. Finite element methods (FEM), electromagnetic analysis of magnetic flux and CFD analysis of MR flow, are wont to determine optimal value of design parameter. a special method is use of magnetic flux and MR flow together and simultaneously specified optimal design values. Two optimal design of MR damper obtained are verified with experiment study by manufacturing and testing of the dampers.

Dewi Utami et al.[12], have mention the properties of M R Damper . The test was in straits 170,000 cycles employing a fatigue dynamic testing machine which has 20 mm of stroke length and 0.4 Hz of frequency. At initial stage the damping force was calculated because the amount of operating cycles increased. Then the change in viscosity of the MR fluid was identified as ITU. At end, the structure all observation of MR particles was done before and after the long-term operation. From these tests, it had been seen that the damping force increased because the amount of operating cycles increases, both when the damper is activate and off. It is also observed that the particle size and shape changed because of the long operation, showing irregular of the MR damper increased by about 44%, compared to the initial force for the on-state condition and 90% for the off-state condition after 170,000 operating cycles.

X.C. GGua et al. [13] With the assistance of compressibility of MR fluid considered, ordinary differential equations of MR damper model are derived in this paper. Then the quasi-static MR damper model connected in series with a spring subjected to compression of MR fluid. Moreover, the spring stiffness expression is found to be equivalent to the oil spring in hydraulic technology. A quasi-static MR model further to a friction element a parallel-connected viscous element, these two basic elements together with a spring together act as dynamic MR damper model. To find out damping force, velocity of MR dampers under sinusoidal displacement, a physical model is developed by considering compressibility of MR fluid.It is found that the hysteresis width of a MR damper is independent of piston area and only a function of spring stiffness for a given sinusoidal displacement.

C. Wu et al. [14] in this paper MR fluid employed in this research is formed by Cheng-Kung. the scale of magnetizable particles is seven micrometers in average diameter and also the carrier fluid is 1000 cps (1Pa·s=1N·s/m2=1000cps) of silicone glue. One property additives of surfactant is adopted to stay magnetic particles float, therefore the appearance of this MR fluid is even dark gray and sensitive to the field. The formula of MR fluid employed in this research is 30% seven micrometers magnetisable particles, 8% surfactant and 62% silicone glue of 1000 cps.In this research, the behaviour of MR dampers has been developed by the modelling, design and experiment. supported the analysis of reduction effects and time-and motion study, it will be seen that there's an improvement of the performance after notice inside the chamber. Therefore, it will be confirmed that the patterns of magnetic lines directly influence the thickness of MR fluid. Enhancement of MR damper depends not only on the manufacture of MR damper but also the rate of excitation. supported this experiments, the capacity of MR damper degrades while the rate of piston rises.

Mark R. Jolly et al.[15] have studied the rheological and magnetic properties of MR-126PD, MRX-140ND, MRX242AS and MRX336 AG and their applications are discussed. MRX-336AG shows greater viscosity at low shear rate compare to other thr9ee fluids. MRX-126PD is having low coefficient of sliding friction. MRX-366AG is having nearly no detectable rate when initial settling is concern. MRX-126PD is well suited for low shear rate while MRX-242AS is best suited for high shear rate application. So MRX-126 is best suitable for heavy duty vehicles seat suspension. MRX-140ND is MR fluid designed for seismic vibrations in structure. MRX-242-AS works best for small sealed devices.

S. K. Mangal et al. [16] An experimental and numerical studies of MR Damper is carried out in this paper. Initially a 2D model is prepared by using Finite element method, ANSYS platform is used to analyse and examine the characteristics of MR Damper. Based on FEM model a prototype model is fabricated and tested experimentally. After comparing these two models analysis shows that the FEM based model is effectively portraying the experimental behaviour of MR Damper in terms of its damping force. This model is more efficient and reliable for designing and analysing MR Damper to predict damping force within the permissible error of engineering analysis.

S.,Huang et al.[17] In his research digital holographic microscopy has presented. The MR fluid in different volume fractions of particles and different magnetic field strength has been measured by this digital holographic microscopy. Here the relationship between volume friction of MR fluid in two parallel discs and shear yield stress, a magnetic field has established, under applied magnetic field based on chain structure of magnetic particles. In this paper three MR fluid samples are taken to check the rheological properties of MR fluid.Then test the equipment of MR fluid to obtain the material parameter. Here publisher obtained the relationship between the shear stress and magnetic induction and particle volume friction.

J. David Carlson et al. [18] it has been studied that, by using external magnetic field the rehological properties are controlled for smart materials that was fluids, Elastomers and foams which has been used in MR damper. MR fluids flow properties has been easily controlled to get variety of vibration control devices. Controllable liquid has been put in an absorptive matrix in MR foams to get high sensitivity applications of MR damper. A rubber like material called MR elastomer whose stiffness can be controlled. The conclusion of this paper is to commercial use of MR fluids based devices in exercise and transportation with high sensitivity.

Peng-yi Wang et al[19] he has performed that MR fluids has been used as forming medium to get variable sheet formability. For sheet formability loading types of magnetic field may affect which has been significantly evaluated in this paper. With the help of bulge tests using three types of MR fluids with various mechanical properties. The dependence of sheet formability has been carried out by finite element results. Forming load with Swift and drop

recovery has been observed which have been used to indicate rapid response of forming load. On the variation of iron particles various magnetic field response curves has been obtained. Conclusion of this paper is, if their is increment of magnetic flux density which results in the hardening effect.

2.3. Work related to Mathematical modeling

Sadak Ali Khana et al. [20] have discussed about various modes of usage and characteristics of MR Damper. Mathematical modelling of the MR fluid dampers based on Bingham plastic model and Herschel Bulkley model are presented. Three modes of operation such as valve, share, squeeze modes are discussed. From mathematical calculation which is done in this paper it is clear that the flow velocity is constant in the plug flow region because the shear stress is less than the yield stress.

2.4. Work related to Cable networking

H. Metered et al.[21] This paper gives the experimental identification of dynamic behaviour of MR damper and evaluated it's controllers. Feed forward and Recurrent Neural Networks has been accustomed model the Direct and inverse dynamics of damper. RNN model as damper controller have experimentally evaluated against conventional damper controller. From this experiment it shows that neural based damper controller gives superior damper control over others. It also provides extended service lifetime of damper and minimum use of sensors, low power requirement. It offers the foremost cost effective vibration control solution over the controller investigated. Neural Networks shows reasonable robustness over significant temperature range.

Duan et al.[22] This research included the study of cable vibration control using MR dampers. Here both theoretical and experimental methods are used. For open-loop control and closed-loop control of rain wind-induced cable vibration the analysis and design method has been developed. The overall study of this paper gives advantages in application of MR based smart damping technology on the cable stayed denting lake bridge. Also this article is very useful for unprecedented smart control technology for protecting and revitalising civil structure.

M. J. L. Boada et al.[23] it has been described the recursive lazy learning method for modelling the MR damper based on neutral network has been considered. In this method select the network structure and calculate model parameters. By using sinusoidal controlled damper piston displacement at constant current level the MR damper characteristics has been measured to determine the behaviour of MR damper. In this method small velocity force variation displays an hysteretic behaviour while large velocity force varied linearly. Conclusion of this paper is to learn cycle quickly. It easily select network structure and previous fitting of parameters are not required

2.5. Work related to Current coil

Benxiang Ju [24] In MR damper the design and analysis of magnetic circuit is an important step. In this paper the effects of different stage coil, same and opposite direction of coil, width of damping channel and the diameter of core is presented. In design of piston assembly, single stage and two stage coil have analysed. The two stage coil has a high performance than the single stage coil as it has more magnetic controlled length in the gap under same excitation condition. The opposite winding direction gives increased effective length of damping channel which is good for damping characteristics. The procedure given for coil winding in this article is helpful in optimising magnetic circuit and designing time.

Fregchen Tu et al. [25] have explained about for automobile suspension a single piston rod MR damper with an accumulator has been designed. The integrated optimal design has been obtained by combining magnetic circuit and structure for obtaining damper structural parameters. By using Finite element method magnetic circuit has been analyzed. The damping force of MR damper with accumulator has been calculated by using formula deviation. It has been experimentally stated that whole volume of all parts of MR damper is

small and weight is low. It should not increase whole magnetic field of MR damper as well as dynamic response is fast. Conclusion of this paper is the multiple structural parameters and magnetic circuit parameters are simultaneously designed at the same time as well with high efficiency.

Bogdan Spinski et al.[26] In his research it has been shown that standard tuned mass damper is replaced by an electrical harmonic oscillator. It has been shown that their is no any requirement to change structural part like mass and spring. Between EEH coil and control coil it has been introduced tune RLC circuit for MR damper. The mechanical resonance frequency is close or equal to electric resonance frequency by selecting appropriate RLC circuit parameters. It is necessary that RLC circuit quality factor greater than 1. EEH induced voltage is lesser than the voltage activated in the MR damper.

Dal-Seony Yoonl et al.[27] In this paper the Eddy current analysis of MR damper have been studied for found response time for damping. For that, by using various equations damping force is calculated for MR damper. By using various core materials for analysing Eddy's current which is responsible for time delay in MR damper. The Soft Magnetic Composite (SMC) is used for inner and outer core material. Because it has been high electric resistivity and also inner core has been machined to reduce amplitude of Eddy current. The experiment has been done on two models were used for analysing the various parameters which causes time delay for damping. Model A consist of both inner and outer core material has been SMC and Model B has been consist of outer core has been made from SMC and inner core has been made from steel. By using Taguchi method it has been experimented. Conclusion of this paper is by using Taguchi method it is find that model A and B are more faster than commercial damper. In the experiment it is find that increase in resistance will increase in power consumption. So it needs to create better current drive for controlling current magnitude.

2.6. Work related to Forces acting on damper

Dr. D.R Pangavhane et al.[28] To understand the hysteretic relations between damping force and velocity a Bouc Wen model and modified Bouc Wen model for MR Damper is presented. The property of MR Damper can be described with Bouc Wen model. So this model is mostly used for modelling of MR Damper. In order to obtain more accurate model modified Bouc Wen model is used in which additional elements dashpot and spring are introduced. This model predicts accurately the behaviour of Damper.

Jin Huang et al.[29] The theoretical investigation of flow behaviour of MR fluid in circular plate MR isolating dampers has been carried out in his research. Here the publisher explains that the MR disk type isolating dampers are the semi-active control devices which use MR fluid to generate controllable squeezing force. This paper reports the analytical endeavour into fluid dynamic modelling of an MR isolating damper. Here by using bi-viscosity constitutive models, the velocity and pressure distribution of an MR fluid operating in an axisymmetric squeeze model are analytically solved. This research paper states that the squeezing force increases with increase in applied magnetic field strength.

Zbynek Strecker et al. [30] Most important parameter which influences the general performance of MR damper is time response. Time response for commercial MR Damper lies within the range of ten milliseconds which is just too long for efficient system. to scale back this point delay modified damper of which piston made from Gerrit bobbin and steel outer cylinder is introduced during this paper. For optimum induction to reminisce the dynamic range for ferrite bobbin and outer cylinder is higher than the time response of ferrite bobbin and steel cylinder gives shorter time response.

Jian Wu, Zhiyuan Liu [31], He has designed half car MR suspensions system by using novel controller. The nonlinear constraints of MR damper are transferred into piecewise constant constraints by using piecewise approximate model. The attenuation of pitch as well as heave responses are satisfied H infinite index by piecewise affine control law. It has been given

linear matrix inequality optimization. It has been shown that skyhook controller has been less effective in the range of 1-4 He as compared to PWA-H infinite controller. The conclusion of this paper is to handle nonlinear actuator of half car MR suspension by using Novel method.

2.7. Work related to Performance of damper

G. Yang et al.[32] This research paper describes the features of MR damper and it's essential advantages. Here the quasi-static axisymmetric model derivation of MR damper is carried out, then it is compared with simple parallel plate model & experimental results. For determining the MR damper performance the dynamic response time is an important factor. This paper also describes the different issues which affect the dynamic performance of MR dampers. As civil engineering is concerned then MR fluid damper is quite promising. The semi active damping for structural applications a large scale MR damper having weight 20 ton is designed and constructed. Here two quasi-static models have been derived for designing with the help of force - velocity relationship of MR damper. The result of all this experiment shows that the MR damper can provide large controllable damping force, while a small amount of energy is required. Also it describes that response time of damper is sufficient for a wide range of civil engineering structural applications.

Ali K. El Wahed et al.[33] the numerical and theoretical methods with experimental validation study have done in his research. This work is for the performance estimation of MR fluid dampers. Here the study of theoretical, numerical and experimental approaches is done to assess performance of a novel smar MR fluid damper. This MR fluid damper is designed with a ball and socket structure. To authorise a multi - degree freedom output of a device. The Herschel - Bulkey model is used for numerical technique and Bingham plastic fluid characteristic for theoretical models. Due to the friction between the balls and lip-seal component, the mechanical torque of the device has been generated. It has been measured experimentally. Also it added in theatrical and numerical torque results. The conclusion of this paper is to confirm the performance of smart dampers, found to be in good agreement with simulated devices performance and estimated theoretically

3. Discussion

MR damper is getting more attention due to their smart handling system to the damped vibration. Their is lot of opportunities to work on the design and analysis of MR damper. By using accurate composition of fluid and proper size of iron particles will increase viscosity of fluid as well as damping ability of MR damper. It will also reduce the consumption of energy required for vibration controlling. The MR damper is smart damper system that is regulating forces acting on the elements of MR damper .By using suitable design of MR damper to increase its efficiency by decreasing cost requirement. There are wide range of applications and scope to work in this field.

4. Conclusion

This overview paper gives information of MR damper, it's use and it's characteristic analysis. Their is lot of advantage of MR damper and wide range of application. Their is huge scope in work in the field of MR damper parts like fluid, eddy current variation and modelling of MR damper. The fluid which is used in MR damper be varied in different composition of oils as well as variation in size of iron particles. The eddy current frequency is varied to get maximum efficiency. There are tremendous application of MR damper like use in automobile for suspension, used in medical field and use in structural building for earthquake prevention. MR damper faults are necessary to detect to get good balancing automobile by using various analysis method like FEA, CFD and Recursive method.

Reference:

[1]D. Q. Truong et al.,"MR Fluid Damper and Its Application to Force Sensorless Damping Control System", (2012), Published on 2012.

[2] H.Sachin, Y.Liu et al. ,"Full-Scale Magnetorheological Fluid Dampers for Heavy Vehicle Rollover",(2007),Journal of intelligent material system and structure, Vol.2007.

[3]Jorge Lozoya Santos, Juan C. Tudon-Martinez,et al.,"Fault detection for an automobile MR damper", (2012),published by Techologico De Monterry, Campus Monterry, Av. Garza Sada 2501,64849,Monterry N.L., Mexico 2012.

[4]A.J.D. Nanthakumar, J. Jancirani, et al. ,"Multiphysics Analysis of a Magnetorheological Damper", (2019),Journal of Defence Science , Vol. 69, No.2019.

[5]Choi,Y.T.Robinson,et al.,"Analysis and Control of a Magnetorheological Landing Gear System for a Helicopter", (2006), Journal of J. Am. Helicopter Society, 2016, 61(3), 01-08. doi: 10.4050/JAHS.61.032006.

[6]Wentao Liu, Yiping Luo,et al.,"Design and Mechanical Model Analysis of Magnetorheological Fluid Damper",(2016),American Journal of Mechanics and Applications,Vol.4,No.1,2016,pp.15-19.doi:10.11648/j.ajma.20160401.13.

[7]A. Ashfak, A. Saheed,et al. ,"Design, Fabrication and Evaluation of MR Damper",(2009),Journal of World Academy of Science, Engineering and Technology 53 2009.

[8]S. K. Mangal and Ashwani Kumar,"Experimental and Numerical Studies of Magnetorheological (MR) Damper", (2014),Journal of Hindawi Publishing Corporation Chinese Journal of Engineering,Volume-2014, Article ID 915694.

[9]G.Z.Yao, F.F.Yap,et al. ,"MR damper and its application for semi-active control of vehicle suspension system",Published at "Mechatronics journal".

[10]Mukai Wang, Zhaobo Chen, et al. ,"Magnetorheological damper design to improve vibration mitigation under a volume constraint",(2011),Published at"IOP Publishing Ltd", Volume 28.

[11]Zekeriya Parlak,Tahsin Engin,"Optimal design of MR damper via finite element analyses of fluid dynamic and magnetic field",(2012),Published at- Mechatronics, volume-22, issue-6.

[12]Dewi Utami , Ubaidillah,"Material Characterization of a Magnetorheological Fluid Subjected to Long-Term Operation in Damper" , (2018),Published at-M.D.P.I.

[13]X.C. Guan,P.F. Guo,et al. ,"Modeling and Analyzing of Hysteresis Behavior of Magneto Rheological Dampers", (2011),Published at-"The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction",14 (2011) 2756–276.

[14]C. Wu, Y.C. Lin and D.S. Hsu,"PERFORMANCE TEST AND MATHEMATICAL MODEL SIMULATION OF MR DAMPER",(2008),Published at-World Conference on Earthquake Engineering.

[15]Mark R. Jolly, Jonathan W. Bender,et al. ,"Properties and Applications of Commercial Magnetorheological Fluids", Journal of Thomas Lord Research Center Lord Corporation 110 Lord Drive Cary, NC 27511

[16]S.K.Mangal and AshwaniKumar,"Experimental and Numerical Studies of Magnetorheological (MR) Damper",(2014),Hindawi Publishing Corporation Chinese Journal of EngineeringVolume 2014, Article ID 915694, 7 page.

[17]Cheng, S. Huang,et al.,"Analysis and testing of chain characteristics and rheological properties for magnetorheological fluid", (2013),Adv. Mater. Sci. Eng., 2013, 2013, 290691 01-06.

18]J. David Carlson, Mark R. Jolly,"MR fluid, foam and elastomer devices",(2000),published by Loard corporation, materials division, 110 Lord Drive, Cary, NC, 27511-7900, USA.

[19]Peng-yi Wang, et al. , "The rapid response of forming mediums properties to variable loading types of magnetic field and consequent field depends sheet formability", (2017),Journal of National key lab for precision heat processing of materials, school of materials science and engineering, Harbin Institute of technology, Harbin, 150001,China.

[20]Sadak Ali Khana,A.Sureshb et al. ,"Principles, Characteristics and Applications of Magneto Rheological Fluid Damper in Flow and Shear Mode", (2014),Journal of "International Conference on Materials Processing and Characterisation",Procedia Materials Science 6(2014)1547–1556.

[21]H. Metered, P. Bonello, S.O. Oyadiji "The experimental identification of magnetorheological dampers and evaluation of their controllers",(2010),Mechanical Systems and Signal Processing 24 (2010) 976–994 .

[22]Duan, Y.F.,et al. , "Cable vibration control using magnetorheological dampers", (2006),Journal of J. Intell. Mat. Syst.Str., 17(4), 321-325.

[23]M. J. L. Boada, J. A. Calvo,et al.,"Modelling of MR damper by recursive lazy learning",(2006),Journal of Mechanical Engineering Department, Automobile Safety Research institute (ISVA), Carlos lll university, Avada, Madrid, Spain 2008 .

[24]Benxiang Ju,"The Simulation and Optimization of the Magnetic Circuit for Magnetorheological Damper",International Journal of Magnetics and Electromagnetism ISSN: 2631-5068 .

[25]Fregchen Tu, Quan Yang,et al., "Experimental study and design on automobile suspension made of MR damper", (2012),Journal of Zhuzhou times New materials science and technology Co.Ltd, Zhuzhou, 412007,China 2012.

[26]Dal-Seony Yoon, Yu-jin Park, et al."An eddy current effect on the response time of MR damper", (2019),Journal of Smart structures and system laboratory, Departments of mechanical engineering, Inha university, Incheon 402-751, Republic of Korea.

[27]Bogdan Spinski, et al. , "Electrical harmonic oscillator with MR damper and energy Harvester operating as TMD:Experimental study", (2020),Journal of Department of process control, AGH university of science and technology, Aleja Mickiewicza 30,30-059 Cracow, Poland 2020.

[28]Nitin Ambhore ,Shyamsundar Hivrale,et al. ,"A Study of Bouc-Wen Model of Magnetorheological Fluid Damper for Vibration Control",(2013),International Journal of Engineering Research ocholog UERT) ISSN: 22740181 Vol. 2 Issue 2013 .

[29]Jin Huang, Ping Wang and Guochao Wan,"Squeezing Force of the Magnetorheological Fluid Isolating Damper for Centrifugal Fan in Nuclear Power Plant" (2012),Journal of

Hindawi Publishing Corporation science and Technology of Nuclear Installations Volume 2012, Article ID 175703,doi:10.1155/2012/175703.

[30]Zbyněk Strecker,J. Roupec,et al.,"Design of magnetorheological damper with short time response",(2015),Article in Journal of Intelligent Material Systems and Structures,June 2015 DOI: 10.1177/1045389X15591381.

[31]Jian Wu, Zhiyuan Liu, "Piecewise affine H infinite control of half car MR suspension system", (2018),Journal of Department of control science and engineering, Harbin Institute of technology, Harbin, China 2018.

[32]G. Yang, a B.F. Spencer Jr. a , et al. ,"Large-scale MR fluid dampers: modeling and dynamic performance considerations",(2002), Engineering Structures 24 (2002) 309–323.

[33]Ali K. El Wahed and Hao Chen Wang." Performance Evaluation of aMagnetorheological Fluid Damper Using Numerical and Theoretical Methods With ExperimentalValidation",(2019),Journal of ORIGINAL RESEARCH published on 2019.*