PERFORMANCE EVALUATION OF ENERGY HARVESTING LINEAR MAGNETO-RHEOLOGICAL(MR) DAMPER

[1]Jeevan Narayan Kalyankar, [2]Prabhakar D. Maskar

[1]M.tech Student, [2]Assistant Professor,
Department of Mechanical Engineering,
Walchand college of Engineering Sangli.

Abstract : The Magnetorheological (MR) damper is made up of two parts: a magnetorheological damper and an energy harvesting system or generator. The vibration energy is dissipated by dampers, which are frequently used in automobiles. When we provide current to an energy harvesting linear MR damper magnetic field produced it modifies the behaviour of the fluid, and it resists motion in the perpendicular direction of the applied magnetic field. Energy harvesting linear MR dampers which having energy harvesting system produce output voltage by using permanent magnet and coil arrangement, where mechanical energy produced by displacement of piston is converted into electric energy. By using ANSYS software analysis of MR damper is done and magnetic field in the case of damper is observed, where MATLAB Simulation model used for determination of output voltage.

Index Terms – MR fluid, Damper, Permanent magnet, copper coil, Generator

I. INTRODUCTION

1. 1 MR Damper

With the development of MR fluid-based devices, particularly dampers, the application of MR fluid has increased fast in diverse industries such as transportation, mechanical engineering, and civil engineering. We know that MR fluid is used inside the dampers, and that when current is applied, varied damping occurs. Magnetic particles suspended in a liquid carrier such as mineral oil, synthetic oil, water, or ethylene glycol are referred to as MR fluids. When a magnetic field is present, however, the iron particles in the fluid create a chain-like structure with the external magnetic field. As a result, there is rearranging of the particles in the fluid which is caused by changes in the applied magnetic field, the fluid viscosity changes. The use of such fluids in energy harvesting dampers allows the damping characteristics of the dampers to be controlled.

1. 2 Energy Harvesting Mechanism

Energy harvesting linear MR dampers by using generator where mechanical energy produced by displacement of piston is converted into electric energy by the means of some arrangement. In conventional MR damper electric energy required for the fluid to change its phase the additional power supply is needed. To reduce this power supply energy harvesting concept used in this linear MR damper. To achieve this, it is necessary to modify the design of conventional damper to produce the electric energy. When the vehicle is moving on the rough roads the displacement of piston of damper is produces that means, generally mechanical energy produces but because of vibration that mechanical energy converted into heat energy and energy is wasted. In this study mechanical energy produced due to the displacement of energy harvesting MR damper's piston head is converted into electric energy. For this conversion of energy, the principle of magnetic field is used. Generator device, consist of permanent magnet and coil arrangement, where permanent magnet connected to the rod of the piston. When piston moves then permanent magnet attached to the piston rod also move in vertically direction and copper coil called induction coil cuts magnetic field and produce power.

Chao Chen and Wei-Hsin Liao [2012] developed a MR damper which generate power having self-sensing ability, where damping and power generation were main focus. For MR damper systems, this model offers advantages like as energy savings, great dependability, and a reduction in size and weight. Integrated relative displacement sensor (IRDS) technology to make MR dampers self-sensing based on electromagnetic induction was studied by **Dai-Hua Wang and Xian-Xu Bai [2013],** as well as the principle of an integrated relative displacement self-sensing MR damper (IRDSMRD) based on the IRDS technology. **Guoliang Hu et al. [2016]** investigated an MR damper with energy harvesting capability, in which a magnetic array and coil move vertically, producing 750 N damping forces at 0.6 A current and generating roughly 1.0 V DC voltage at 0.06 m/s. The effects of the magnetic flux density created in the fluids flow gap were investigated by **Hemanth Krishna1 et al. [2017].** They work on maximising the magnetic flux density by optimising the electromagnetic circuits of an MR damper. There is a significant rise in magnetic flux density when the fluid flow gap is less than 1.12 mm. The magnetorheological (MR) damper was invented by **Raju Ahamed et al. [2017]** based on its energy harvesting capacity, which includes energy generation from lost energy of piston displacement and magnetorheological dampening. To generate energy, the energy harvesting device uses a copper coil and a permanent magnet configuration. The MR damper with serial-type flow channels was studied by **Guoliang Hu et al [2019]** where they calculated total damping force damping performance had tested and analyzed under different parameter like applied frequency excitation applied current, and amplitude. They use MRF-J25T fluid for the experiment purpose and ANSYS software used for simulation. **Madhav Avhad and Prabhakar Maskar [2020]** conducted an experiment and a theoretical analysis on a magnetorheological damper or magnetorheological shock absorber, which is filled with magnetorheological fluid and regulated by a magnetic field, which is normally created by an electromagnet. The performance of the MR damper is determined by the fluid flow gap, magnetic field, percentage of iron particles, and percentage of additives. In addition to the Taguchi optimisation method, an analysis of variance is utilised to determine the most relevant parameter. **Urvesh Kabariya and Sagil James [2020]** used the energy harvesting concept to test an MR damper in a parallel arrangement for a vehicle system. The study entails a lot of designing, numerical simulation, construction, and testing of the model. Were focused on creating a hybrid smart suspension system. The proposed damper was created using CATIA V5 software. MRD 132DG oil and a Neodymium N48 magnet were used in this experiment.

1. 3 Components of MR damper and Generator

1.3.1 MR Fluid: The fluid in the damper is known as MR fluid, which stands for Magneto-Rheological fluid. Smart fluid, such as MR fluid, is now used inside dampers to offer variable damping when current is applied. In the presence of a magnetic field, the iron particles in the fluid form a chain-like structure with the external magnetic field. As a result of the rearranging of the particles in the fluid caused by changes in the applied magnetic field, the fluid viscosity changes. The use of such fluids in energy harvesting dampers allows the damping characteristics of the dampers to be controlled.

1.3.2 MR Damper: We know that vibration is harmful to vehicle which cause failure of some components of vehicle, so damper or shock absorber are used to reduce the vibrations.

1.3.3 Generator or Energy Harvesting Mechanism: The generator device is made up of a permanent magnet and a copper coil called induction coil, where neodymium magnet which fitted on rod of the piston of generator. When piston moves then permanent magnet attached to the piston rod also move in vertically direction and copper coil called induction coil cuts magnetic field and produce power.

II DESIGN AND DEVELOPMENT OF MR DAMPER

For design purpose we chose a gap size and active pole length to meet the dynamic range and controllable force the dynamic range is [6]

$$D = \frac{F}{F_{un}} = \frac{F_\tau + F_n + F_f}{F_n + F_f} \qquad (1)$$

F = Resisting force offered by damper, F_τ= yield stress force, F_n = Viscous force, F_f = Friction force, Fuc= Uncontrollable force. Knowing the value of the friction force before the damper is built and tested is challenging. However, we can assume that $F_{h}= F_f$ and $F_t + F_h \gg F_f$ so friction force at numerator is not consider because it is very small as compared to sum of shear force and viscous force at denominator, we consider viscous force and friction force both are equal and add them now equation become,

$$D = \frac{F}{F_{un}} = \frac{F_\tau + F_n}{2F_n} \qquad (2)$$

$$2D = \frac{F_\tau + F_n}{F_n} \qquad (3)$$

For the experimental purpose we select MR-122EG fluid

τ=20 kPa = 0.020 N/mm^2, $R2$ = 25 mm, LT = Total length of piston = 55 mm

For most of the MR damper design situations it is necessary to have the controllable force comparably more than uncontrollable forces. In general, the dynamic range *D* selected for design of damper is taken to be 10 that is the controllable force is 10 times to that of uncontrollable force. Hence equation becomes [6]

$$2D = \frac{(d_p/d_x)_{\tau=0}}{(d_p/d_x)_{\tau 0=0}} = 2 \times 10 = 20 \qquad (4)$$

Now from the Gap vs Ratio of pressure drop table we get gap (h) of 1.5 mm the value of 2D is 22.06 which satisfy equation, so we select gap of 1.5 mm and by using gap value we calculate diameter of piston head which is equal to inner diameter of cylinder minus 2h is,

$R1 = R2 – h$ = 25-1.5

$R1$ = 23.5 mm

that means the diameter of piston head is 47 mm and by using some empirical relation we get diameter of piston rod. λ is the ratio of the diameter of the rod to the diameter of the piston cylinder of the MR damper, value of λ is 0.4 to 0.5 for the double-cylinder, and 0.3 to 0.35 for the single-cylinder in this case we use single cylinder, so value is selected is 0.3,
$47\times 0.3 = 14.16$
But according to standard value we select 16 mm diameter of piston rod.

2.1 Magnetic circuit design

when input current supplied to excitation coil which is bound on piston head which produce magnetic field and then this magnetic field changes behavior of MR fluid from liquid to semi solid. To achieve a better result and an optimal design of the magnetic circuit fluid gap, the magnetic field must be maximized while energy loss in steel and non-working areas is minimized. The overall amount of steel in the magnetic circuit should be kept to a minimum. However, adequate steel cross-section must be maintained to keep the magnetic field intensity in the steel material to a minimum.

For design, we use the properties of MR-122EG, and we conclude that for obtaining fluid yield stress Is 20 kPa that is 0.02 N/mm^2. Then from fig 1 that magnetic induction vs Yield stress graph we get magnetic induction in fluid (Bf) of 0.4 Tesla.

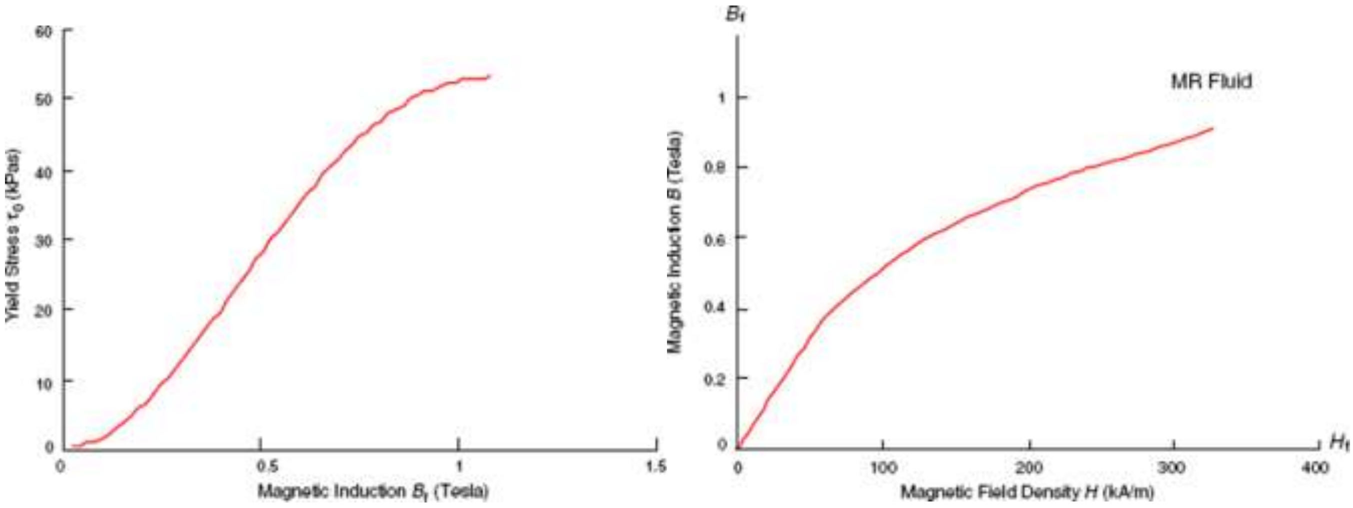

Figure 1 yield stress versus Magnetic induction in MR fluid and 2 Induction versus field density for MR fluid [6].

From Fig 2 magnetic field density (Hf) required in fluid for induction of 0.4 Tesla is 80 kA/m.

Now the total magnetic induction flux is calculated as follows [6],

$$\Phi = Bf \times Af \quad (5)$$

as the flux in steel and fluid is same, we have,

$$\Phi = Bf \times Af = Bs \times As$$

$$Bs = \frac{BfAf}{As} \quad (6)$$

Af = Effective pole area =Circumference of piston x Length of piston, Af = 3.14 x 47 x 55, Af = 8116.9 mm^2

As = Circumference of piston x Length of piston where flux lines crosses fluid path= 3.14 x 47 x 20, As = 2951.6 mm^2

Bs = Magnetic induction in steel

$$Bs = \frac{BfAf}{As} = \frac{0.4 \times 8116.9}{2951.6} = 1.1 \text{ T}$$

Hs = 0.6 kA/m

The required number of amp-turns (NI) can be calculated using Kirchhoff's law for magnetic circuits[6].
Now,

$$NI = \sum H_i L_i = H_f g + H_s L \quad (7)$$

$NI = 80e^3 \times 3e^{-3} + 0.6e^3 \times 101e^{-3}$

$NI = 300.8$

For 5 A current we calculate number of turns N as

$$N = \frac{300.8}{5} = 61$$

2.2 Material selection for manufacturing cylinder assembly

Next important thing is to select the material of damper assembly in order to have minimum resistance to magnetic flux lines (they should have good magnetic properties) piston and cylinder of MR damper made up of mild steel. To concentrate the magnetic flux along the piston the material for piston rods is taken to be stainless steel which is non-magnetic. The coil excitation coil bound around piston head taken as copper coil. The damper's cylinder and piston are composed of mild steel, whereas the piston rod is stainless steel, as detailed in the material selection section. Copper material is used for the winding.

2.3 Ansys Model of MR Damper

Following figure shows Ansys model of piston with coil arrangement which show Magnetic flux density. Where maximum value of magnetic flux density is 1.2183 T and minimum value is -0.777 T.

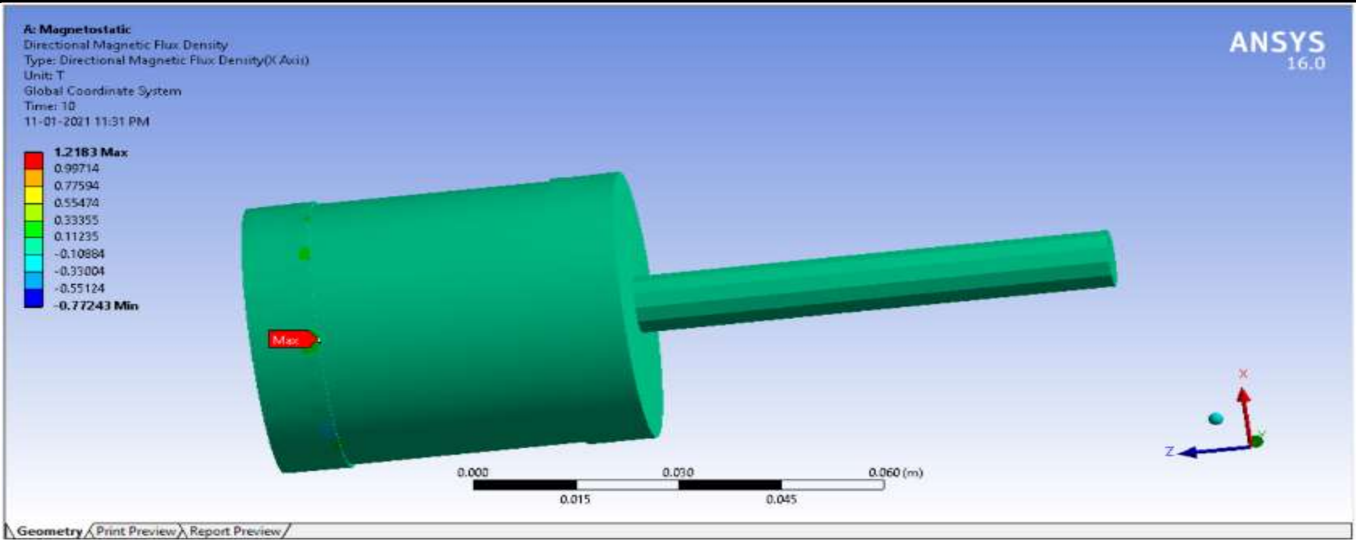

Figure 2 Ansys Model of MR Damper

2.4 Calculation of Damping Force

Now we find damping force so formula of damping force is given bellow, Ap is the area of the piston in normal operating condition, S is the shear yield strength of MR fluid 20 kPa, which is 0.020 N/mm2, where piston's relative speed indicated by, L is the length of the effective damping in mm, P is the average circumference of channel where damping is occurred, in mm, h is the width of damping gap in mm, and D is the dynamic viscosity of MR fluid of 0.042 N.s/m and which can be expressed as[7]

$$F = \frac{12\mu l A_P^2}{\pi P h^3} v + \frac{3 l A_p}{h} \tau_y \quad (8)$$

Table 1 Following table shows damping force value at different displacement value.

Displacement (mm)	Velocity (mm/min)	Damping Force (N)
10	100	613.23
20	100	1226.40
30	100	1839.22
40	100	2452.95

III DESIGNS OF GENERATOR

Generator devices consist of permanent magnet and coil arrangement, where permanent magnet connected to the rod of the piston. Because of the displacement of the piston, neodymium magnet also move, and the copper coil of the power generator harvests power by cutting magnetic flux which is produced by the permanent magnet. ϕ is a magnetic flux which is in weber, B_{rem} and H_c are the material properties of the permanent magnet, where B_{rem} is a remanent flux density of the magnet and H_c Magnetic field intensity of the magnet or Coercivity.

3.1 Calculation of Induced Voltage

To find voltage induced in coil following formulae are used. Where μ_o is the relative permeability, which is $4\pi \times 10^{-7}$ H/m, A_g is the surface area of the cylindrical air gap and Am is the magnet's cross-sectional area. now θ phase angle. To calculate induced voltage, use the formulas below[4].

$$\phi = \frac{B_{rem}\tau_m\mu_o H_c A_g}{2gB_{rem} + \tau_m\mu_o H_c \frac{A_g}{A_m}} \quad (9)$$

$$A_m = \pi((S + l_m)^2 - s^2) \quad (10)$$

$$A_g = \pi\left(S + l_m + \frac{g}{2}\right)(\tau_m) \quad (11)$$

ϕ =magnetic flux of air gap where leakage is not considerd in weber

B_{rem} = remanent flux density of the magnet

τ_m =thickness of the magnet mm

μ_o =Relative permeability = $4\pi \times 10^{-7}$ H/m.

H_c =Magnetic field intensity of the magnet or Coercivity (KA/m)

g= air gap length in mm

$A_{g=}$ surface area of cylindrical air gap mm^2

A_m =cross-sectional area of the neodymium permanent magnet mm^2

S= diameter of the shaft mm

z= displacement of the piston mm

θ= phase angle 180^0

$\frac{dz}{dt}$= velocity of the piston mm/sec

Here E is induced voltage in volt and N is the number of turns.[4]

$$E = -N\phi \frac{\Pi}{\tau} Sin\left(\frac{\Pi}{\tau} z + \theta\right) \frac{dz}{dt} \qquad (12)$$

3.2 MATLAB Simulation of Generator

Here is the MATLAB Simulation of Generator is shown

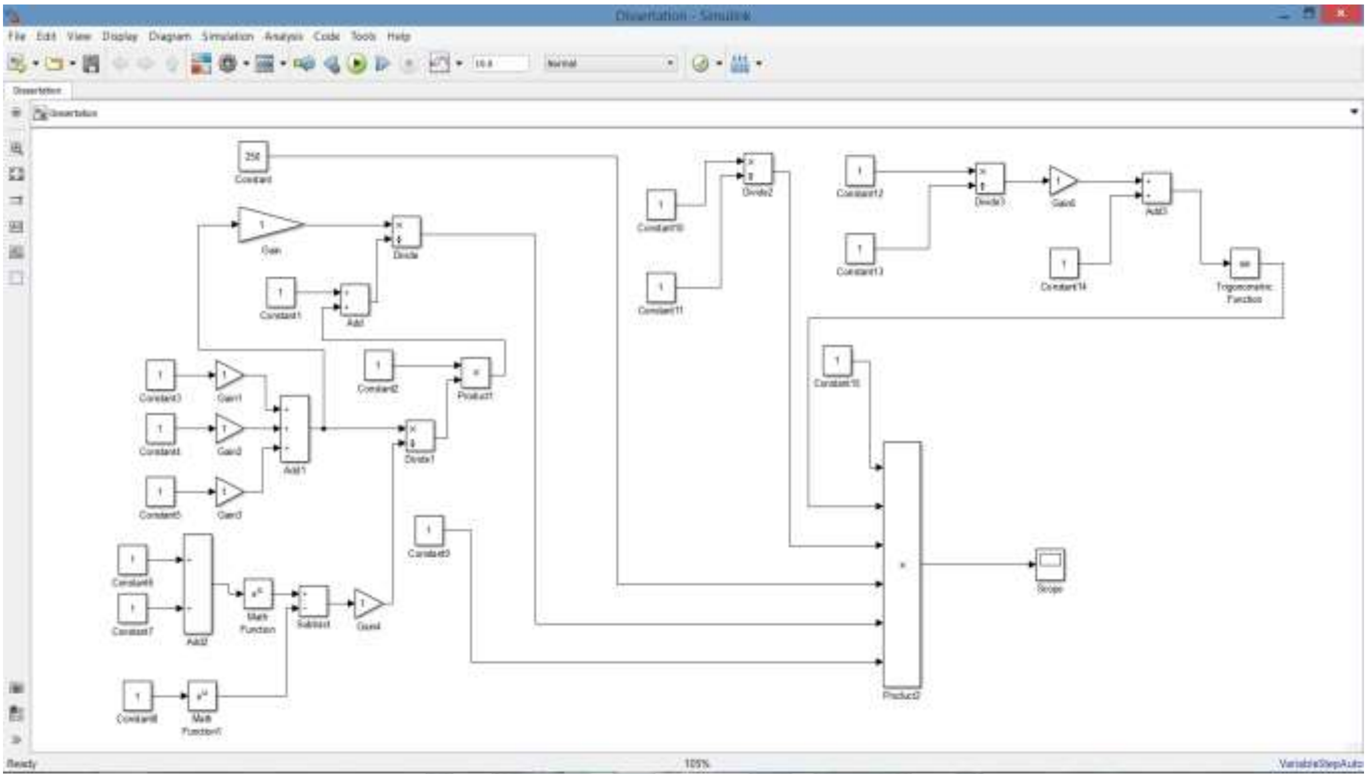

Figure 3 MATLAB Simulation of generator.

Table 2 Induced voltage at displacement and velocity

Displacement mm	Velocity mm/min	Output voltage (v)
10	100	0.8
20	100	0.808
30	100	0.825
40	100	0.835
10	200	1.6
20	200	1.62
30	200	1.65
40	200	1.68

IV CAD MODEL OF DAMPER AND GENERATOR.

Fig 4 show the cad model of MR damper and Generator is given bellow. Where left side fig shows assembly of damper in which copper coil mounted on piston head and right, side fig shows generator assembly where magnets mounted on rod and cylinder of generator having copper coil wound on it.

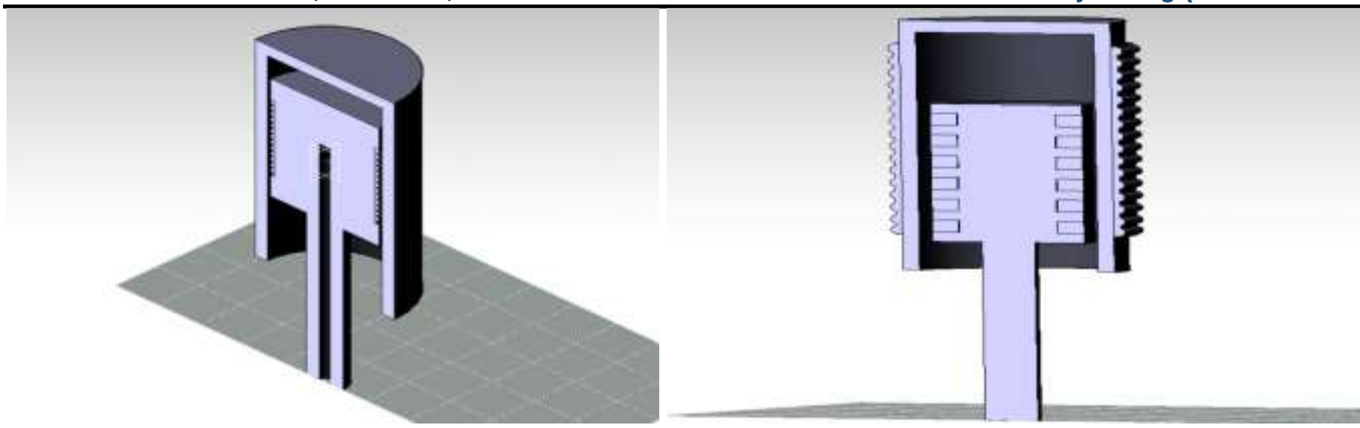

Figure 4 Cad model of damper and Generator.

V CONCLUSIONS

1. When displacement and velocity increases damping force increases.
2. When we increase displacement and velocity the output voltage which produced by using coil and permanent magnet, is also increases.

VI ACKNOWLEDGEMENT

I would like to offer my special thanks to Prof. P.D. Maskar for his valuable guidance. I would like to extend my appreciation to all who directly or indirectly help me in completion of this work.

VII REFERRENCES

1. Chao Chen, Wei-Hsin Liao- “A Self-Sensing Magnetorheological Damper with Power Generation.” Smart Material Structure. 21 (2012) 025014 (14pp)
2. Dai-Hua Wang, Xian-Xu Bai- “A magnetorheological damper with an integrated self-Powered Displacement Sensor” Smart Material Structure 22 (2013) 075001 (14pp)
3. Bogdan Sapinski- Energy-Harvesting Linear MR damper: Prototyping and Testing Smart Material Structure 23 (2014) 035021 (15pp)
4. Guoliang Hu, Yun Lu, Shuaishuai Sun, and Weihua Li- “Performance Analysis of a Magnetorheological Damper with Energy Harvesting Ability”, Shock and Vibration Volume 2016, Article ID 2959763
5. Raju Ahamed, MM Rashid, MM Ferdaus and Hazlina B Yusuf - “Modelling and Performance Evaluation of Energy Harvesting Linear Magnetorheological (MR) damper” Journal of Low Frequency Noise, Vibration and Active Control (2017) Vol. 36(2) 177–192.
6. Sapramer Hamirbhai Rewabhai,’’ Design and Development of Magneto Rheological Fluid Base Damper’’, Thesis submitted to Gujarat Technological University,2017
7. Guoliang Hu, Hao Liu, Jinfu Duan and Lifan Yu- “Damping performance analysis of magnetorheological damper with serial-type flow channels” Advances in Vibration Control of Structures and Machinery 2019, Vol. 11(1) 1–12
8. Madhav Avhad & Prabhakar Maskar - “Design Optimization of Magneto-Rheological (Mr) Damper for Vehicle Suspension System” 2020 JETIR August 2020, Volume 7, Issue 8
9. Urvesh Kabariya & Sagil James- “Study on an Energy-Harvesting Magnetorheological Damper System in Parallel Configuration for Lightweight Battery-Operated Automobiles” Vibration (2020).
10. John C. Dixon- “The Shock Absorber Handbook”, Senior Lecturer in Engineering Mechanics. The Open University, Great Britain.