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Analysis of a Magnetorheological Fluid Damper

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Abstract:- A Magnetorheological fluid can be implemented on a suspension system for damping of shock as a replacement for conventional oil dampers which has a constant viscosity.

When a magnetic field is applied, the viscosity of MR fluid varies. Due to variable viscosity the damping action of the damper can be modified as per requirement which not only increases the comfort level but also optimizes vehicles performance suspension life.

Keywords:- *Fluid damper; Suspension system; CAD modelling; Magnetorheological damper; reverse engineering;*

I. INTRODUCTION

A shock absorber or damper is a mechanical or hydraulic component modelled to absorb or dampen shock impulses which are caused due to external disturbances. The kinetic energy of the shock is transformed into a different form of energy which is then dissipated to the surrounding environment. Pneumatic and hydraulic shock absorbers are used in combination with cushions and springs.

In a vehicle, a damper deals with the effect of going through rough and wavy roads which results in enhanced ride quality, vehicle handling, and comfort. When modelling or selecting a shock absorber one of the most important factors is how the energy can be dissipated to the external environment or where that dissipated energy will go. The sole purpose of a shock absorber is to dampen spring oscillations. Shock absorbers use valving of oil or gasses to absorb excess energy from the spring. Most of the conventional oils have a fixed viscosity which gives constant damping in all situations and all directions.

A magnetorheological fluid can be implemented in these suspension systems for damping of shock in the damping system as an alternative for conventional oil dampers which has a constant viscosity. When a magnetic field is applied, the particles align themselves along the lines of magnetic flux, which modifies the viscosity of MR fluid. Due to variable viscosity the damping action of the damper can be adjusted as per the given requirement which not only amplifies the comfort level but also optimizes vehicles performance and increases the automobile suspension life.

Magneto-rheological fluids are free flowing liquids having consistency similar to that of motor oil. Magneto-rheological fluid acts as a regular, steady flow fluid in the absence of magnetic field, but when subjected to a magnetic field which can be induced through a current carrying coil or permanent magnets, the fluid amplifies its apparent viscosity to the point of being a viscoelastic solid. This so happens because the iron particles in MR fluid acquires a dipole moment with the external field which causes particles to form linear chains parallel to the field, as shown in figure 1.1. This phenomenon can solidify the suspension ferrous particles and prevent the fluid movement as per the given requirement.

A. History

The Telesco Shock Absorber, displayed at the 1912 Olympia Motor Show and marketed by PolyrhoeCarburattors Ltd, was one of the first hydraulic dampers to enter production. This damper used a spring inside the telescopic unit, similar to pure spring type shock absorbers,' but also used oil and an internal valve to dampen the oil in the rebound direction. The Telesco unit was installed behind the leaf spring, in place of the rear spring to chassis mount, as part of the spring system. This layout was chosen because it was simple to implement in existing automobiles, but it resulted in the hydraulic damping only being applied to the action of the auxiliary spring in the unit, rather than the action of the main leaf spring.

In case of Magneto-rheological fluid dampers, the technology was primarily developed by General Motors Delphi Automotive Division based in the USA and then developed further by Beijing West Industries in China after Beijing West Industries bought the technology from General Motors. Post-acquisition of the technology, Beijing West Industries has introduced modifications including a redesigned ECU and the introduction of a dual coil system.

B. Motivation and problem definition

A suspension system is the collection of parts that work together to isolate the vehicle from road shocks. It includes the springing device as well as various mounting options. The spring oscillates due to the energy of the road shock. The damper, also known as a shock absorber, reduces these oscillations. The flexibility and stiffness of a springing device must be balanced. Springs are used to connect the road wheels to the body. When the wheel hits a rut in the road, it rises and deflects the spring, storing energy. Because of the elasticity of the spring material, it rebounds when released, expending the stored energy. In this manner, springs begin to vibrate, with the amplitude gradually decreasing due to internal friction of the spring material and friction of the suspension joints, until the vibrations cease.

Fluid flows through an orifice in a Magneto-rheological fluid type suspension system, which can be restricted by applying a magnetic field across it. Magnetic domains suspended in fluid make up the fluid. The damper is made of ferromagnetic material, which allows the magnetic field to influence the magnetic domains of M-R fluid. When a current is applied to an electromagnetic coil located outside the shock absorber's piston, the resulting magnetic field changes the viscosity of the fluid, resulting in a very responsive and controllable damping action that does not require any valves.

The intensity of the magnetic field has an effect on the viscosity. This property is frequently used in commercial vehicles to provide various modes of performance depending on the condition.

II. MAGNETORHEOLOGICAL FLUID

Magneto-Rheological (MR) dampers are a new type of damper that employs controllable Magneto-Rheological Fluid (MRF). MRF is a smart material made up of micron-sized ferromagnetic particles suspended in a water-based solvent. Magnetic flux can be used to control the rheology of MRF. Copper wires wound around a ferromagnetic core are used to generate the required magnetic flux density. Weight, power consumption, and response time are the most important factors to consider when designing these dampers..The particles in the base carrier fluid, showsudden changes in rheological properties in the presence of a magnetic field and the MR fluid changes state from a free flowing fluid to a solid state. This process is reversible by eliminating the magnetic field.

A. Composition of M-R fluid

a) **Base liquid:** solvent, often a carrier oil, is a non-magnetizable liquid that combines lubricating and damping properties. To enhance the MR effect, the carrier oil should be of low viscosity and temperature insensitive, so that the MR effect is the major factor in causing shear stress during the off-state. Hydrocarbons, minerals, silicon, and hydraulic oils; silicone copolymers, polyester, polyether; halogenated organic liquids, diesters, polyoxyalkylenes, fluorinated silicones, and glycols are all examples of liquids that can be used.

b) **Ferro-magnetic particles:**The MR effect is caused by the alignment of these particles along the line of the magnetic field. Iron, iron/cobalt alloys, iron oxides, iron nitride, iron carbide, and carbonyl iron are the most commonly utilized magnetic particles. The magnetic materials can take up to 50% of the overall volume.

c) **The additives**: Additives are shear thinning chemicals having the ability to reduce friction and reduce corrosion/wear. To prevent clumping, dispersion agents such as ferrous naphthanate or ferrous oleate areutilized.Surfactants, nanoparticles, nano magnetizable particles, and coated magnetizable particles are just a few of the additives that can be employed in MR fluids.

B. MR fluid magnetic behaviour

Electromagnets only magnetise in the presence of external magnetic fields; a solenoid wound around an iron core is an example of one of these magnets. Magnetic fields are created by the movement of electrical charges, such as electric current. Magnetic fields are typically generated using solenoids or wounded coils. A solenoid with a soft magnetic core behaves similarly to a simple magnet, with one end of the coil representing the North Pole and the other representing the South Pole. The total magnetic field is calculated by superimposing the magnetic fields generated by all the turns.. For a solenoid,the magnetic flux density of center of core and magnetic field intensity can be calculated from

$$B = \mu . H$$

$$H = \frac{NI}{\sqrt{4r^2 + l^2}}$$

The formula for magnetic flux density, magnetic field intensity and magnetization is given below:

$$\mu = \mu_r . \mu_0 . \qquad M = \chi_m . \mathrm{H}$$

$$B = \mu_0 H + \mu_0 M \qquad \mu_r = 1 + \chi_m$$

Where M is Magnetization,□□ is magnetic susceptibility,□□ is relative permeability of the soft magnetic material, and is used to extent of material magnetization, and □0 is the permeability of vacuum.

The magnetic characteristics of an MR fluid may be deduced from its B H and M-H hysteresis curves.

When an external magnetic field is added, the static yield stress of MR fluid increases significantly. Once aligned, the iron particles become magnetised and resist migrating out of their respective magnetic fields. Aligned magnets operate as a barrier to an external force; hence, a shear stress or pressure differential is required to break this structure. Under stress, the fluid opposes flow at zero shear rate. Meanwhile, the force generates a plastic deformation since there is no continuous movement. The yield stress is the greatest tension that may be applied under this circumstance without generating continued movement. As previously stated, the strength of MR fluid, known as static yield stress, grows nonlinearly as the magnetic field intensity increases.

C. Rheological properties of MR fluid

The quick liquid-to-solid transition, hydrodynamic forces, carrier oil viscosity, electrostatic forces, and particle size and shape all contribute to the unique rheological behaviour of MR fluids. In the absence of an external field, MR fluids behave similarly to typical Newtonian fluids, implying that the dynamic viscosity of Bingham plastics is usually constant. When operating in the off state, MR fluids appear to have similar apparent viscosities as liquid paint (0.1– 1 Pa. s 1 at low shear rates).

III. METHODOLOGY AND PROCEDURE

A. Reverse engineering

The modelling of conventional damper was done by the study and measurement analysis of a car damper. A conventional oil damper of Maruti Suzuki Swift Dzire Car was used. Oil used in this suspension system varied from SAE

10W to SAE 30W. The different parts of the damper were dismantled to the smallest single component whose imagesare shown in the following pictures:


Fig.1: Encasing for the damper mechanism


Fig. 2: Damper mechanism


Fig. 3 : Washers and the piston head

Each part was measured carefully and the following dimensions were found.Using these dimensions, a CAD model of the conventional damper was made in order to perform the flow simulation. The dimensions of the main components are as follows:

Part	Outer Diameter (mm)	Inner Diameter (mm)	Height (mm)
Cylinder	330	300	250
Piston	30	-	15
Piston Rod	198	-	294

Table-1: Components Dimension

Material of Damper: Steel

B. *CAD Modelling*

Drawing of the main components are given below with their respective dimensioning.

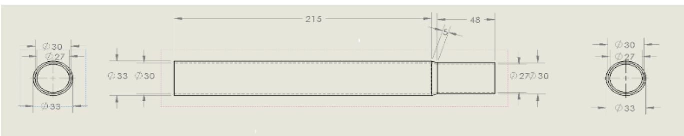
Fig. 4 : Drawing of the Cylinder

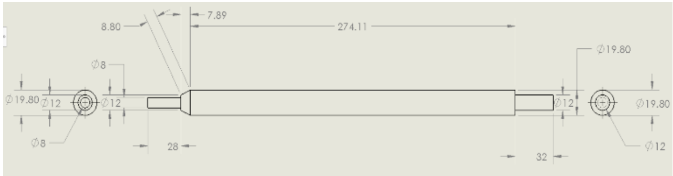
Fig. 5 : Drawing of the Piston Rod

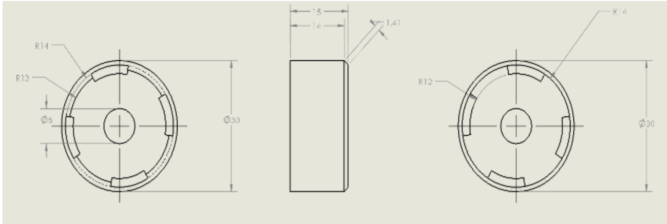
Fig. 6 : Drawing of the Moving Piston

Parts of the hydraulic damper were created in SOLIDWORKS using the dimension found from the reverse engineering process. The following figure shows the assembly of the hydraulic damper


Fig. 7: Drawing of the Assembly

C. *Modelling of Quarter Car Suspension*

The Quarter Car Suspension model was created using a dimension of a real car and necessary changes were made for the easy and smooth design. The dimensions were measured for the modelling and drawing. The following table shows the dimension of links and tyres.

Part	**Dimension**	**Specification**
Tyre	300	Diameter
Upper Link	165	Length
Lower Link	265	Length
Distance b/w links	174	-

Table-2: Quarter Car Suspension Specification

The following figure shows the drawing of the quarter car suspension model where each part of the model is assembled together.

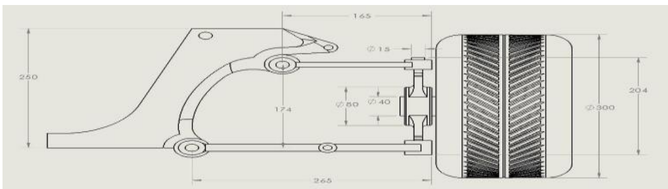
Fig. 8 : Drawing of the Quarter Car Suspension

A 3-D model was created in SOLIDOWORKS using the dimensions given in the table. The other dimensions were found by the measurement of the actual car suspension model. The following figure shows the Quarter Car Suspension Model.

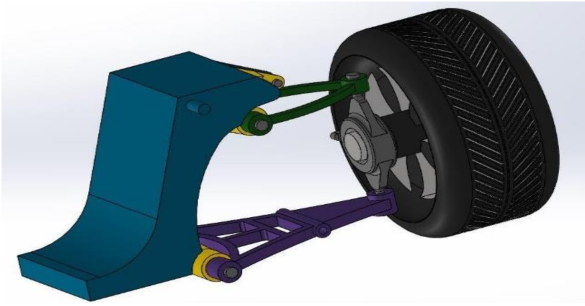

Fig. 9 : Quarter car suspension Assembly

D. Simulation of Quarter Car Suspension Model

The same model was imported to the MSC ADAMS Software and necessary constrains were made to perform the simulation. The following figure shows the picture of the model imported.

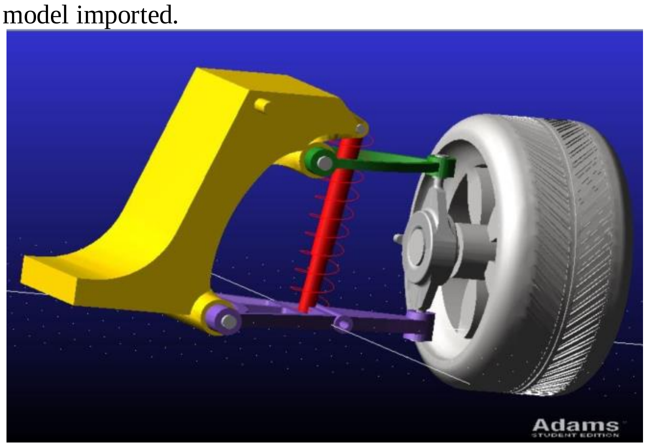

Fig. 10 : Model in Adam software with constraints

E. MATLAB Analysis

Based on the suitable equation for solution of our problem, a MATLAB code was written to show and verify the Relation between EDC, Current, and Displacement.

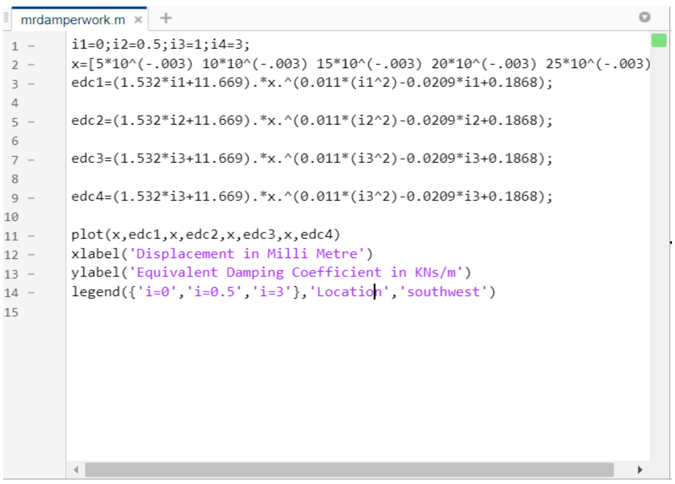

Fig. 11 : MATLAB code

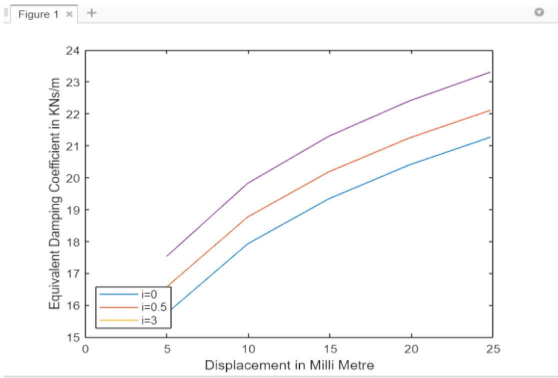

Chart 1: Graph Displacement-Equivalent Damping coefficient

IV. RESULTS

A. MATLAB Results

It shows the change of equivalent damping coefficient (in KNs/m) against the displacement (in mm) with varying current at 0, 0.5 and 3.

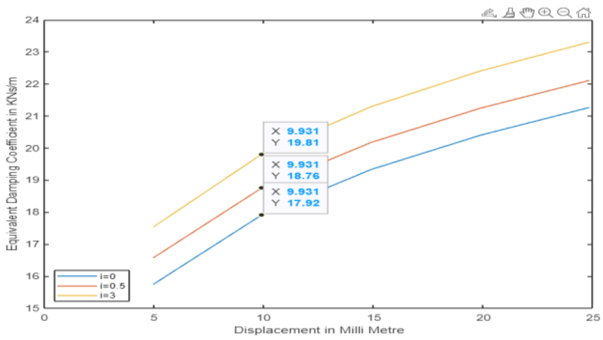

Chart 2 : Equivalent Damping Coefficient vs Displacement

Average Percentage Change in EDC:
(((19.81-18.76)/18.76)/2.5)+(((18.76-17.92)/17.92)/0.5)/2)*100= (((0.04875/2.5)+(0.055970/0.5))/2)*100= **6.572**%((KNs/m)/Ampere

B. Simulation Results

The graph between the force vs time were obtained along with a superimposed graph of deformation forceand velocity vs time which is shown in the following figure.

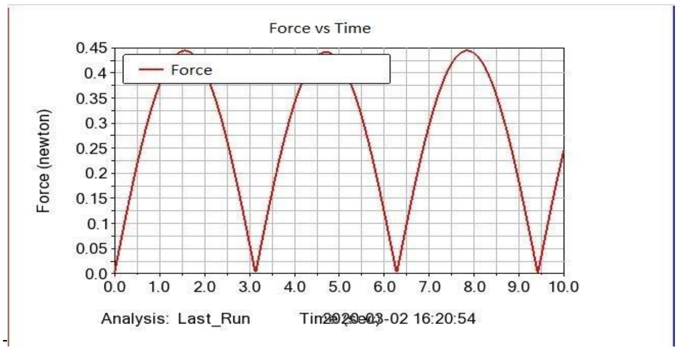

Chart 3: Force vs Time

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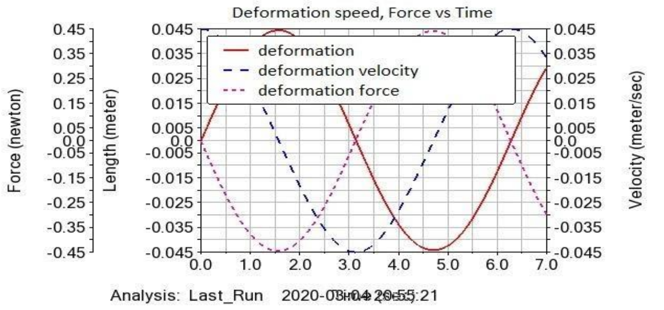

Chart 4 : Deformation Force and Deformation velocity vs Time

V. CONCLUSIONS

The MR Fluid Dampers changes viscosity when subjected to changing magnetic field, this change in magnetic field can be created by changing current passing thru solenoid. By MATLAB Analysis of MR Damper Mathematical Model, it was found that:

- Increasing current increases the Equivalent Damping Coefficient of System.
- When no current is passed MR Fluid Damper behaves as conventional damper.

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