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Design and Development of Damper for Semi-Active Suspension System

Saurabh S. Kulkarni*1, Pankajkumar R. Bodade*2, Ashutosh G. Hetkar *3, Ajit Patil*4, Sameer Agrawal*5

#*Mechanical Department, Savitribai Phule Pune University*

[1]*twain5502@outlook.com*

[2]*pankajkumarbodade95@gmail.com*

[3]*hetkarashutosh121@gmail.com*

Abstract

Conventional suspension system is specified in terms of viscosity of the damper which can't be changed. Force transmitted to the damper by the conventional suspension system is slightly high. Varying the properties of the damper according to the force applied can improve the stability of the vehicle. To design and manufacture cost-effective MR fluid damper for semi-active suspension system. In this work, we designed and manufactured an MR Damper, analyzing the damper in ANSYS for different metals/alloys and selecting the final material considering higher magnetic saturation, lower cost involvement and adequate strength of the damper. First, the damper is designed considering a certain amount of load, analyzed for different materials, then magnetic circuit is designed accordingly. This work is focused on optimum vibration mitigation and material selection while keeping costs low.

***Keywords*— MR Damper, Magnetorheological Fluid, Design and Manufacturing, Magnetic Saturation**

I. INTRODUCTION

Generally, there are three types of suspension systems- Active, Passive and Semi-Active. In passive systems, the damper or the fluid cannot be controlled as per the varying conditions. In active systems, the damper as well as the fluid are controlled according to the varying road conditions, but these systems tend to be expensive and only get used in higher end cars. Semi-Active suspension systems on the other hand combine the advantages of active suspension systems with the lower costs and lower complexity of passive systems.

Principle of working of semi-active systems: As the system detects the road conditions,

In most automobiles today, passive dampers are used, which don't adapt to the road conditions. When forces act on the vehicle, for example, during cornering, the suspension system may not be able to adjust according to the forces acted upon it, causing the car to roll at high speeds. The objective of this project is to experiment on the different materials that can be used for a magnetorheological damper for a semi-

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active suspension system, so as to optimise it for low cost that may aid in its wide adoption. In their study, Fengchen Tu, Quan Yang, Caichun He, Lida Wang have mentioned major automobile manufacturers like GM, Audi, etc. using MR dampers in their suspension systems. The design of an automobile suspension accompanying an MR damper includes a magnetic circuit design and structure design. The magnetic circuit will help regulate the electromagnetic field around the damper. In a mono-tube damper, the shock-absorbing components are contained within one shell-case (tube). This damper consists of a cylinder, in which the viscous fluid is contained, and the piston pushes down on the fluid as forces act on it. A spring helps return the suspension to its original position.

Damping force was very low for zero current and it increases gradually with increase in current. Similarly, controllable current was non zero for zero current also, it means yield stress never become zero. A single piston rod damper with an accumulator in order to satisfy the demand of automobile front suspension system has been developed. In their work the authors Nicola Golinelli, Andrea Spaggiari have designed and manufactured a novel magnetorheological (MR) fluid damper with internal pressure control. The yield stress τ_B of MR fluids depends both on the magnetic field intensity and on the working pressure. Since the increase of the magnetic field intensity is limited by considerations like power consumption and magnetic saturation, an active pressure control leads to a simple and efficient enhancement of the performances of these systems. Finite Element Analysis of Damper was performed by Alan Sternberg, Juan Carlos de la Llera, Rene Zemp in their study, and concluded that force-velocity and force-deformation of an MR-damper can be correctly predicted by the use of FE numerical models using this cascade solution of the magneto-static and fluid dynamics problem.

The presented work has focused on design and development of MR Damper for deployment in commercial use vehicles.

II. MR DAMPER

An MR (magnetorheological) material is fundamentally different in practice from an ER material, because the realistically achievable shear stress is much higher for MR, e.g. 50 kPa, more than one order of magnitude better than ER. As a result, the design of an MR damper can be more conventional, with the valve in the piston, although the piston size is increased somewhat from a normal damper. The magnetic field is generated by the axial coil, for which connecting leads are conveniently brought out through the rod.

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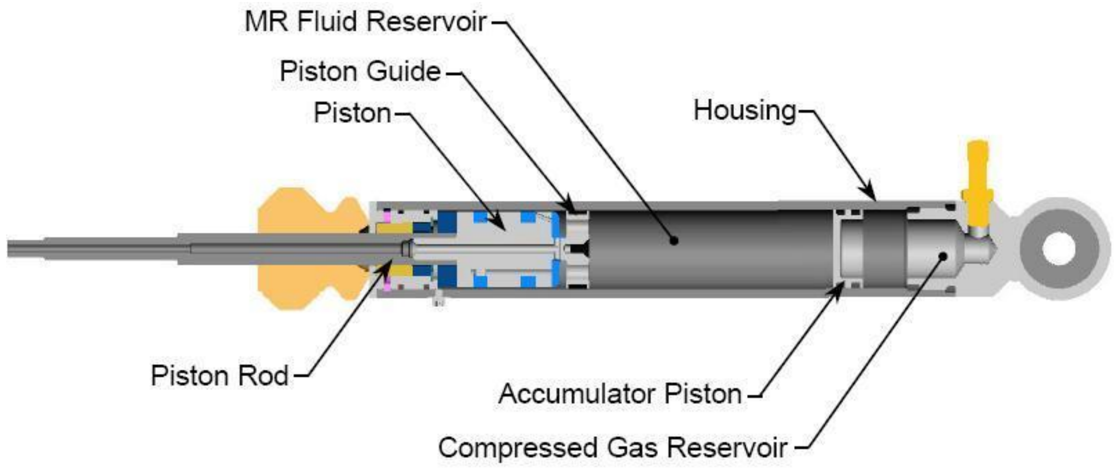

Fig. 1: Typical MR Damper

For best results a low-carbon steel with high permeability and high flux saturation level is desirable. For an air-gap electromagnet, the gap has high resistance relative to the iron (the material permeabilities being in a ratio of 1000 or more), so a gap of any significance dominates the circuit resistance. For an MR liquid, the permeability may be quite high (it may be 80% iron), and a careful magnetic circuit design is necessary.

The flux passes through the coil axially, expands radially outward through the disc at one end, through one MR fluid gap, back along the iron sleeve, radially inward through the disc at the other end and back into the core completing the circuit.

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Design of a magnetic circuit is more complex than for an electric current circuit because of the nonlinear behaviour of the materials, and nowadays is likely to be done using a suitable software package. However, a linear model analysis, as will be done here, is useful for preliminary design and gives useful understanding and an appreciation of the units and numerical values. To change damping based on certain physical measurements like, velocity or acceleration, in order to better counteract and control the system dynamics, the real time adjustable systems can be developed. It has been observed that, the MR damper applications typically use the pressure driven flow (valve) mode of the fluid, or a combination of valve mode and direct-shear mode. Direct-shear mode is applicable for the dampers which do not require much force whereas, for high force requirement, mostly dampers with pressure driven modes can be used.

There are three modes of operation of MR Dampers as shown in figure 2:

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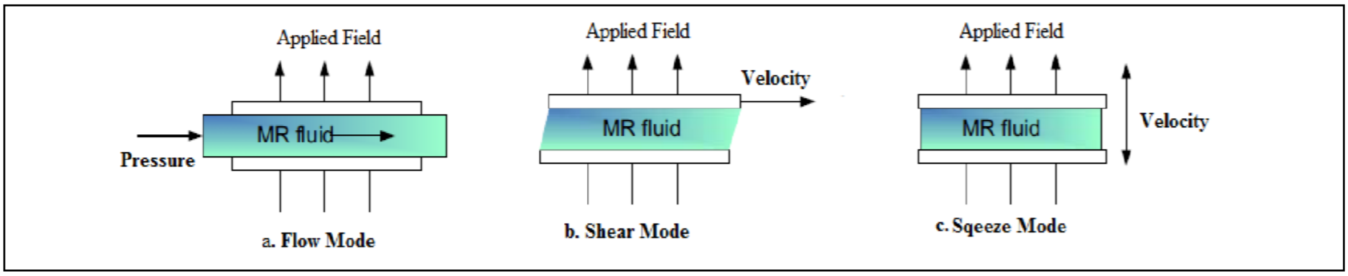

Fig. 2: Modes of Operation of MR Damper

III. MR Materials

A magnetorheological (MR) material is one for which the rheological properties, such as yield stress and viscosity, depend upon the magnetic field.

MR liquids are sometimes described as ‘low voltage’ in contrast to ER liquids, but this is misleading. They are not subject to any voltage, only to a magnetic field, but the field is generated by a current of order one amp at low voltage in an field coil external to the liquid.

As with an ER liquid, the MR liquid is formed by suspending numerous small solid particles, typically a few micrometres in diameter, in a low-viscosity mineral or silicone carrier oil. The average diameter is about 8 mm with a normal range of 3–10mm. The solid particles are ferromagnetic, basically just soft iron.

Fibrous carbon may be added, and also a surfactant to minimise settling out. The result is a very dense ‘dirty’ grey to black oil. The shear strength achievable with magnetic field on is typically 50–100 kPa at fields of 150–250 kA/m. The magnetic activation is not sensitive to electrical conductivity, so temperature has less effect than for ER devices.

Small iron particles are used in many applications, including in the manufacture of tapes for tape recording, magnetic computer discs, and so on. The desired size is small by mechanical standards, much smaller than iron filings, so the iron powder is prepared chemically. Iron oxide may be reduced with hydrogen to form the powder directly. Alternatively, the carbonyl route may be used.

Heating iron pentacarbonyl gas causes decomposition back to iron and carbon monoxide. Under the right conditions, the resulting iron vapour condenses into the desired very fine spherical particles, mostly 1–45mm in diameter, of high purity, 97% and better, with some traces of metal oxides, carbon and air, and good electromagnetic properties. The good sphericity makes for a powder with free flowing characteristics.

The carbonyl process can be controlled to produce powder with a fairly tight size distribution, having a particle mean diameter of 8 mm and standard deviation of about 2mm. The individual particles have a layered ‘onion’ structure and are hard on the surface, which makes them less oxidisable (more corrosion resistant) than would otherwise be the case.

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The almost pure iron particles that result is sometimes called carbonyl iron, which is not a chemical term, but a very misleading name, really meaning iron-from-the-carbonyl. Other names include CIP (carbonyl iron powder) and ferronyl iron. The particles used in MR dampers are just small iron spheres, not iron pentacarbonyl.

A magnetic circuit is analogous to an electric circuit. In the latter case, an electric potential around the circuit (from, e.g., a battery) measured in volts (V) produces a current in amps (A). According to the local cross-section of the wire, there is a local current density (A/m2).

Locally, the current density is related to the electric field strength in V/m (volts per metre) by the electrical conductivity (A/V m). In most circuits the analysis is greatly simplified by using lumped parameters such as a resistor with a specified resistance, voltage and current, rather than dealing with current densities and fields.

The magnetic circuit has a magnetic potential (e.g. from a coil with a current) measured in amp-turns (units just A). The result is a magnetic flux around the circuit measured in webers (Wb). According to the local cross-sectional area of the circuit there is a local magnetic flux density measured in tesla (T, which is just Wb/m2).

The local flux density is related to the local magnetic field strength (A/m) by the permeability (Wb/A m, the same as henry per metre, H/m, 1 H¼1 Wb/A). The magnetic circuit is most easily understood in terms of its physical parts, each of which has a magnetic reluctance, analogous to electrical resistance. Reluctances add in series and parallel in the same way as do resistances.

The permeability of vacuum is= $4\pi x10^{-7}$ H/m. For air, the value is effectively the same. Ferromagnetic materials have a high value, possibly several thousand times as large. The ratio of the absolute permeability to the permeability of a vacuum is called the relative permeability. The relative permeability of MR fluids is typically around 5 or 6. The high iron content can be imagined to almost short out the reluctance, which depends mainly on the oil gaps between the iron spheres, about 1/6 of total distance.

IV. DESIGN OF DAMPER

For a standard MR damper, the following specifications can be assumed:

Piston geometry

Rod diameter= 22.000 mm

Piston diameter = 38.000 mm

Piston- EN8 (Medium Carbon Steel)

Fluid Properties

Relative permeability = 2000.000

MR fluid Density = 2000.000 kg/m3

Viscosity = 300.000 mPa s

Rel. permeability = 6.000

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Yield stress of MR Fluid, τ_B = 20 kPa

Magnetic Coil

Coil Number of turns = 500

Damper velocity = 0.500 m/s

Coil current = 1.00 A

Design of Damper

Shear Force acting on the damper is given by $F_d = F\tau + F\eta + F_f$,

Where F_f=Friction force acting on the damper,

$F\tau$=Controlling Force

$F\eta$=Viscous force

The controlling force, $F\tau$ is given by $F_\tau = \frac{cA_A L_P \tau_B}{g} sign(V_d)$

Where Lp= Length of groove or axial activation length of piston,

A_A = Effective cross section area of piston.

c = Coefficient which depends upon volumetric flow rate, viscosity and yield stress. g= Fluid gap

Cross sectional area of piston, A_A is given by, $A_A = \frac{\pi}{4}[(Piston\ Diameter)^2 - (Piston\ Rod\ Diameter)^2]$

The viscous force is given by $F_\eta = \frac{12k\eta Q L A_A}{wg^3}$

Q = Rate of flow of fluid,

η = Viscosity of fluid

w = Mean circumference of annular flow path,

k = Constant depend upon volumetric flow rate and velocity, taken as 1.06

The friction force of the system can be assumed to be equal to 250N.

The *dynamic range* is defined as the ratio of the total damping force to the uncontrollable force, and according to a general thumb rule, should be greater than 3. It is calculated as Dynamic Range= $\frac{F_D}{(F_\eta + F_F)}$

From the inputs, viscous force comes equal to 259.122N, from which controlling force can be obtained equal to 1490.87N (assuming total shear force equal to 2000N).

The dynamic range obtained is 3.9283, and the length of groove is 27.46mm.

The designed damper assembly is shown in fig. 3.1, the piston rod, cylinder, cylinder lid are shown in figures 3, 4, 5, 6 respectively.

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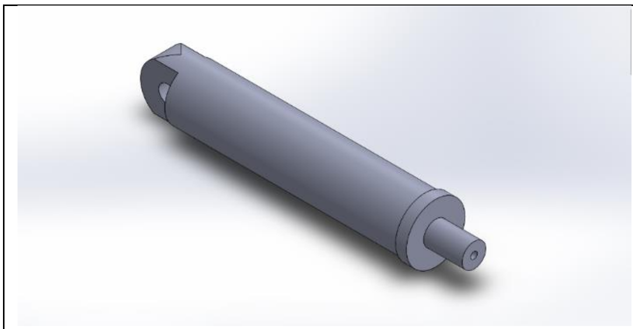

Fig. 3: Assembly of Damper

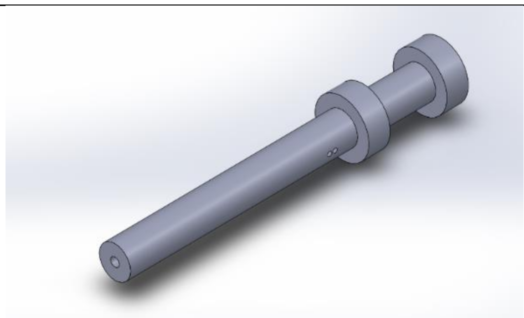

Fig. 4: Piston Rod

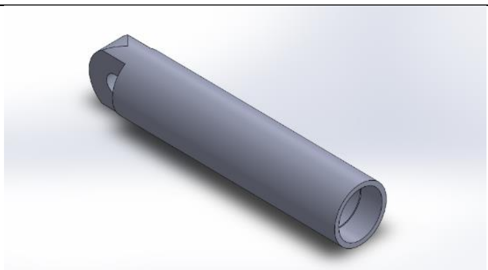

Fig. 5: Cylinder

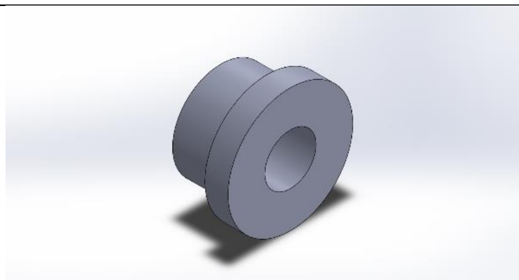

Fig. 6: Cylinder Lid

Piston of MR Damper is wrapped into a magnetic coil. Holes are provided to pass the coil inside the cylinder. The function of piston in conventional damper and MR damper is same i.e. to force the fluid through valves or annular space. As shown in fig 4, a groove is provided on piston surface for coil. The required dimensions of groove were designed. The single tube cylinder as shown in fig 3.3 is used in this work. A lid (shown in figure 3.4) is provided to prevent the flow of liquid out.

Design of Magnetic Circuit

The main aim of magnetic circuit design is to determine the necessary number of turns of the magnetic coil to develop the required magnetic field which in turn develop the required damping force. The iron particles may saturate because of the high flux density; hence care is taken to provide the sufficient cross section for the iron around the coil.

Magnetic Reluctance (R_m)

It is the property of a material which is in magnetic equivalence with the electric property of resistance. The lower the reluctance, it is easier for the magnetic flux to flow through the core material. The materials which are easily magnetized have a low reluctance and high permeability and non-magnetic materials have low permeability and high reluctance.

Reluctance can be given by, $R_m = \frac{l}{\mu A} = \frac{l}{\mu_r \mu_0 A}$

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Permeability of medium carbon steel = $1630\mu_0$ = 0.00512 H/m, Permeability of free space (μ_0) = 4π x 10^{-7} H/m, Permeability of MR fluid (μ_r) = $6\mu_0$ = $75.39\text{x}10^{-7}$ H/m.

Total magnetic potential F is given by $F = \Phi\ (R+\frac{1}{A_g})$

Where R=Total Reluctance,

A_g=Magnetic Permeance

Φ= Magnetic Flux, assumed equal to 3 Weber

Number of turns of coil is given by

N=F/ (Max. current in the circuit)

Number of turns is calculated as 300.

For 300 turns, diameter of copper wire is selected as 0.40 mm.

V. ANALYSIS OF DAMPER

The analysis of damper is done in the CAE tool ANSYS workbench. For analysis, 3-D meshing is done with tetrahedron's and hex elements. Good mesh will give you perfect or better results. By this analysis we will get idea about our model dimensions and its capability to sustaining the amount of force and give us idea if there is any facture is occurred in the damper with its position. So, the analysis of damper is important process in this project.

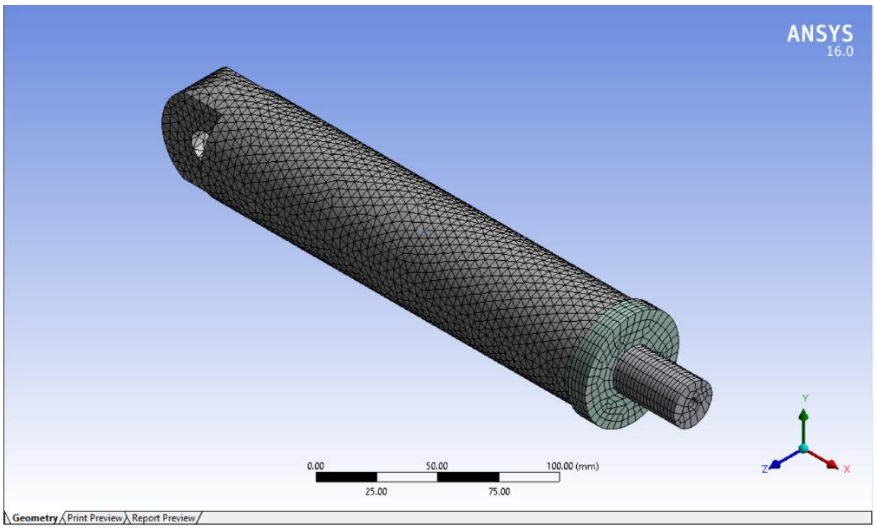

Fig.7: Meshing model of Damper

In the analysis we have considered the mechanical properties such as total deformation, stress, etc. of damper. For the analysis we have taken fixed support at the bottom and applying force of 2000N on the piston rod. The analysis will give us maximum deformation and maximum stress induced in the damper. It also gives its position of maximum stress and maximum deformation occur in the damper. The value

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of mechanical properties i.e. Deformation and stress, etc. is shown with the help of colour codes. This analysis will help in validating the model of damper.

In this analysis report we have seen the maximum deformation is shown by red colour code while dark blue shows the minimum deformation. The maximum deformation occur after full load i.e. 2000N is applied on the damper vertically downward and the damper deform by 0.0053535mm. The maximum deformation takes place at the top of piston where force is applied which is shown by red colour.

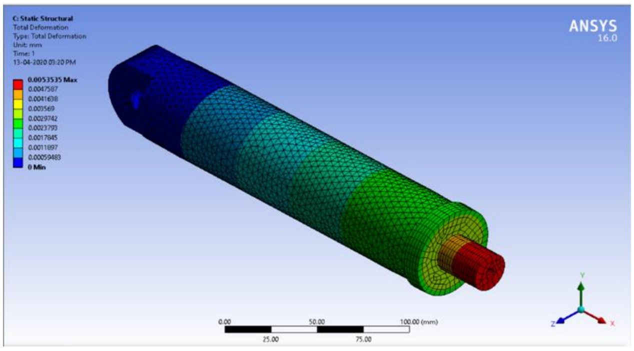

Fig.7: Total Deformation of Damper

The below fig. Shows the stress induced in the damper with the position where the max. And min. Stress is induced. Likewise, total deformation stress induced in the damper is also given by colour codes, where maximum stress shown with red colour and minimum stress is shown with dark blue colour. As we have seen from fig. 7 the maximum stress induced in the damper is 9.8012MPa whereas the minimum stress induced in the dam0er is 2.9319e-9MPa which is at the bottom and top of the cylinder. For the analysis we have considered von Mises stress only; because The von Mises stress is used to predict yielding of materials under complex loading from the results of uniaxial tensile tests. The von Mises stress satisfies the property where two stress states with equal distortion energy have an equal von Mises stress.

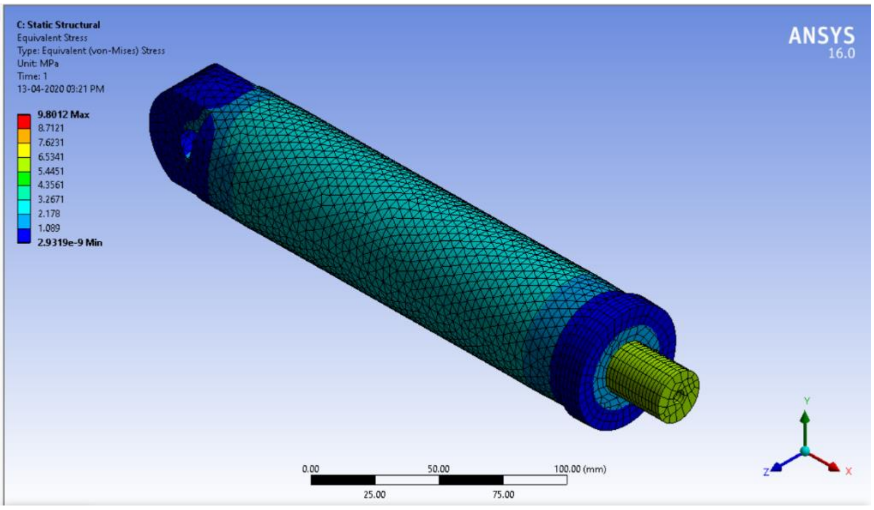

Fig.7: Stress of Damper

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VI. Manufacturing of Damper

The damper was manufactured keeping the cost of material in mind. Four materials were analysed: Monel, Invar 36, Low Carbon Steel and EN08 (Medium Carbon Steel). Invar 36 is the best material for piston considering its higher magnetic saturation level relative to the generally used low carbon steel, but the material costs are more than what can be feasible for a damper to be designed for a cost effective semi active suspension system. Finally, Medium Carbon Steel was chosen owing its lower cost and availability, while having almost higher magnetic saturation level than low carbon steel. The cylinder and the lid meanwhile were made from Stainless Steel 410.

Two 3mm holes were drilled on the piston body to provide an outlet for the wire, which is inserted from the downside of the piston as shown. Outer threads are provided on the lid and inner threads on the cylinder ensure a tight fit. A DC wire of length 2 metres was wound in the piston groove, which would provide the electromagnetic effect for the changing the viscosity of the oil.

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