Study of Electromagnetic Damper

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***Abstract* - This paper discussing all the design for electromagnetic damping systems for passenger vehicle. Electromagnetic damping system is the alternative for existing conventional damping system that uses passive system. In case of electromagnetic damping, repulsive magnetic force between two electromagnets can be used to absorb shocks created due to uneven surface conditions of roads. The parameters related to electromagnets such as current, No. of turns can be varied to match road conditions. This paper deals with the design, fabrication & analysis of electromagnetic damper. The reliability of damping system can be further checked by comparing performance of it with practically used viscous damper.**

Key Words: Electromagnetic damping, Passive damping, Repulsive magnetic force, Road conditions.

1.INTRODUCTION

The use of a suspension system on an automobile has two main objectives: to reduce the accelerations felt by the passenger while traversing a roadway and to maximize the tire contact with the road. The predominant suspension technology is the use of passive dampers and springs to isolate the passenger cabin. While these decrease the passenger acceleration at low frequency of the automobile system, they increase the passenger accelerations at higher frequencies. This increase in passenger acceleration is greater for lightweight vehicles and has historically been a problem.

Modern technologies to overcome these limitations include the use of magnetic elements. Modern dampers in vehicles use magnetorheological fluids that are subjected to magnetic fields generated by electromagnets. While this produces significant advantages over a purely passive damper, it also increases the system complexity and leakage problems which may affect the performance of a vehicle. One of the simplest designs for an electromagnetic damper consists of two electromagnets placed opposite to each other having repulsive force between them. To be considered as effective in this application the damper should use a minimum of electrical power, have a light weight and reduce the passenger acceleration while increasing the force between the road and the tire and it should be better at all of these elements than an equivalent commercial passive damper.

1.1 Objective of the paper

To develop mathematical model and to design an electromagnetic damping system to overcome problems of commercially used passive viscous damping system.

2. WORKING PRINCIPLE

Magnetic repulsion can be used to absorb shocks and since response is very fast, its use can give beneficial results. Magnetic repulsive force can be produced by use of electromagnets. Electromagnets are created by wounding wire on any electricity conducting metallic bar. Current carrying wounded wire will produce magnetic field around it and its direction can be determined by right hand rule. No. of magnetic lines passing through conductor is called as flux. Flux produced in area perpendicular to the magnetic field is called as magnetic flux density and is measured by unit Tesla.

When vehicle moves on the road, irregularities present causes vibrations. Electromagnetic dampers provide damping action through repulsive force between two electromagnets present in suspension system. Wheels then trace a path of irregularities. Entire process would take fraction of seconds. Extra shocks would be absorbed by passive coil spring. Performance of electromagnetic damper can be improved using electronic sensors. Damping force can be varied according to road conditions by varying current and distance between magnetic poles. Permanent magnets can be used but its costs more than electromagnets and in case of permanent magnets, damping force cannot be varied.

3. DESIGN OF ELECTROMAGNETS

To maintain same size as commercially used viscous damper, we proposed a design with same spring and support ends and just replacing piston cylinder arrangement with two electromagnets facing opposite to each other. No. of turns on electromagnets are back calculated according to inside diameter of compression spring. Size of core of electromagnets are again back calculated according to required No. of turns to create sufficient repulsive damping force.

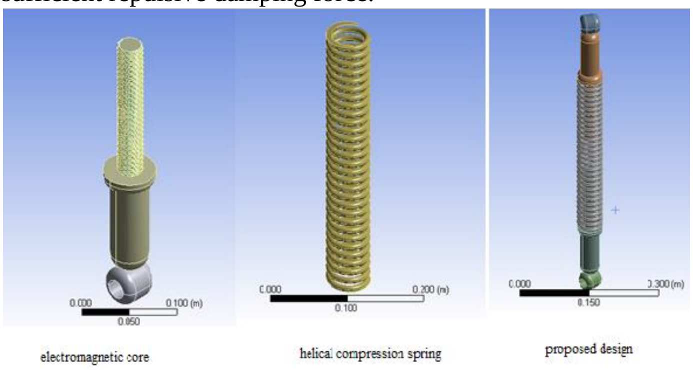

Fig -1: Proposed design of damper using SolidWorks 2012

3.1 Core design

Core of electromagnet is nothing but the carrier of magnetic field along its length. If air is present at the center of coils, then this electromagnet is called as solenoid. For effective magnetism, there should be conducting material at the center of coils to carry magnetism.

3.1.1 Design of core material

To determine material for core of electromagnet, relative permeability criteria is used. Permeability is measure of ability of material to support formation of magnetic field within itself.

Relative permeability is the ratio of permeability of material to permeability of free space. Higher the relative permeability, greater is the ability to develop concentration of magnetic field.

Table -1: permeability of materials

Material	Permeability (H/m)	Relative Permeability
Vacuum	1.25e-6	1
Wood	1.25e-6	1
Teflon	1.25e-6	1
Aluminum	1.25e-6	1
Stainless steel	0.002	1500
Mild steel	0.0025	2000
Iron	0.0006	500
Mu metal	0.025	20000
Nickel	0.000126	150
met glass	12.6	10000000

Considering cost, availability & performance, we chose mild steel as a core material. Met glass can be used, but it cannot be machined according to our requirements. Dimensions of core are obtained from back calculation according to spring design.

3.1.2 Shape of core material

Magnetic flux is inversely proportional to cross sectional area. Hence magnetic flux density will be maximum at minimum cross-sectional area. To verify this, we performed an experiment. We have taken two shapes: taper bar & stepped bar for maximization of flux density. We measured flux density at each end. We coiled 100 turns on each bar. As flux density varies inversely with area of cross section. We got greater magnetic field at an end with reduced cross section area. We got expected results. Magnetic flux density was found to be maximum at small end. For same conditions of No. of turns, power supply & dimensions, we understood that performance of taper bar is better than stepped bar. Hence, we chose taper bar for further experimentation.

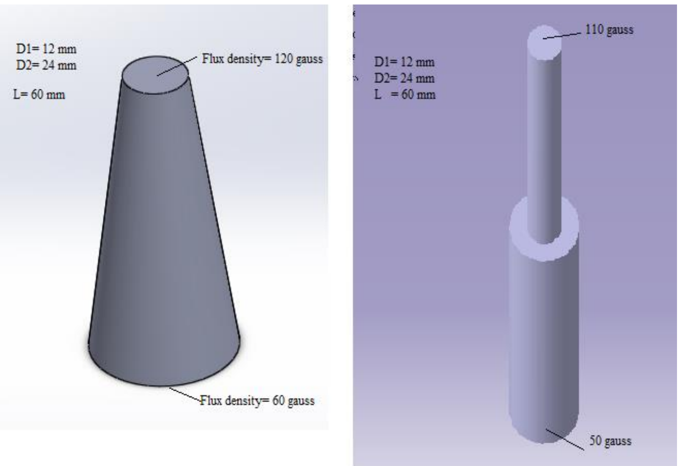

Fig -2: Experimental results about shape of core

3.2 Design of coil

For the coil we need good conductive material with appropriate size.

3.2.1 Coil material

From table, we can have Silver as a coil material having high conductivity. But based upon material's availability, cost and sizes. We have selected copper as coil material being highly conductive, cheap & easily available.

Table -2 Conductivity of materials

Material	Conductivity (W/mK)
Silver	420
Copper	380
Aluminum	200
Steel	40
Fiber glass	0.048
Polyurethane	0.024

3.2.2 Size of coil material:

We needed to fit entire electromagnets into existing spring. We made taper bar for core with 24 mm larger diameter & 12 mm smaller diameter.

3.2.3 Calculation of gauge according to No. of turns and maximum Amperage of coil

Table 3- AWG sizes

AWG	Diameter in mm	Max. Amperage (A)
12	2.053	41
14	1.628	32
16	1.291	22
18	1.024	16
20	0.812	11
22	0.644	7
24	0.511	3.5
26	0.455	2.2
28	0.321	1.4
30	0.255	0.860

We wanted to pass maximum of 3 A current for safe testing. Hence, we selected 24-gauge copper wire with 0.5111 mm diameter and max. amperage of 3.5 A.

3.2.4 Calculation of max. No. of turns possible

Spring inside diameter D_i = 40 mm

Maximum available diameter = D_i – clearance
= 40-10
= 30 mm

Length of each core = 100 mm

No. of turns possible along length $= \frac{100}{0.511}$

= 195

Clearance between spring & electromagnet = 5 mm

Assume Core diameter = 24 mm

Width of wire wound = (40-24-5×2) mm
= 6 mm

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No. of turns possible along width $= \frac{6}{0.511}$

$= 11$ (rounding off)

Total No. of turns possible $= 195\times11$
$= 2145$

Considering thickness of insulation, we wounded 2000 turns on each electromagnet and machined a tapered bar with 24 mm max. diameter.

3.3 Design of spring
Material: Steel (modulus of rigidity) $G = 80000\ N/mm^2$

Mean diameter of a coil D $= 48$ mm

Diameter of wire d $= 8$ mm

C = spring index $= 60/10$
$= 6$

Total no of coils n $= 18$

Outer diameter of spring coil D_o $= D + d$
$= 56$ mm

No of active turns N $= 18$

Solid length, L_s $= n\times d$
$= 18x8$
$= 144$ mm

Free length of spring, $L_f =$ solid length+ total axial gap + δ
$= 2\times18+2\times8$
$= 250$ mm

Pitch of coil $= L_f/(n-1)$
$= 13$ mm

Free length $= pn+2d$
$= 2\times18+2\times8$
$= 250$ mm

Solid length $= dn + 2d$
$= 8\times18+2\times8$
$= 160$ mm

Total coils $= n+2$
$= 18+2$
$= 20$

Spring constant (K) $= \frac{Gd}{8nc^3}$

$= \frac{8\times10^4\times8}{8\times6^3\times18}$

$= 20576.13$ N/m

4 DEVELOPMENTS OF DESIGN

4.1. First proposed design
At initial stages, we had decided to take wooden plate on which electromagnet is proposed to be mounted at center and another wooden plate with same arrangement of electromagnets were to be designed. To guide upper mount, four guides with springs on them were to be designed.

4.1.1 Problems raised in model
Practically used shock absorber has only one spring and our proposed model had 4 springs used. Hence model was needed to be improved.

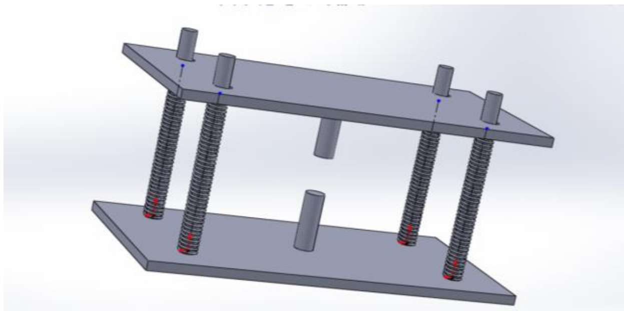

Fig- 3 first proposed design

4.2.2. Improved model
To sustain such a large amount of vibrations, base should be strong. We designed base to accommodate 4 guides and central damper model. Base should be rigid and should isolate vibrations. We designed base on SolidWorks 2015. Shock absorber is to be fitted at centre of this base. Shock absorber used is of Honda Livo bike. Upper mount is attached with four end bearings to have relative motion between guide and upper mount.
Also, to replicate road conditions and vibrations, we used eccentric loading on motor. We used top plate to attach motor. Vibration parameters are measured by acceleration sensors attached near the motor.

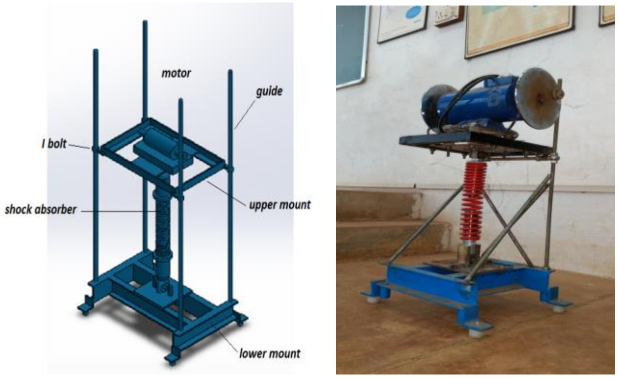

Fig- 4 Revised Design and Practical Model

5. CONCLUSIONS
It is observed that the damping action of viscous damper decreases at resonance condition while there is no effect of resonance on electromagnetic damper. From above research it can be concluded that electromagnetic damper can replace viscous damper for better ride comfort. Better performance can be obtained if combined with electronic sensors. The research

clearly explains that damping action can be varied according to road conditions. Permanent magnets can be used as two repulsive poles but their damping action cannot be varied according to road conditions and they cost way more than electromagnets.

On the other side electromagnetic damping needs continuous power supply. There may be chances of sticking of dirt particles to it due to magnetization. Damping force acting due to repulsion is only in one direction, while in case of viscous damper it acts in both directions hence gives good shock absorbing ability.

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