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A PRELIMINARY STUDY, DESIGN AND CONSTRUCTION OF A REGENERATIVE SHOCK ABSORBER

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Abstract- *Road vehicles expend a significant amount of energy in undesirable vertical motions, which, however, have great importance and prospects in the transportation field. The rising of gasoline prices is now an emerging global threat, especially in the automobile sector. So, many engineers and researchers are trying to help drivers to cut fuel consumption by turning their shock absorbers into a source of energy. This project work aims at the energy recovery in vehicles by using new suspension technology, regenerative shock absorber. It consists of housing and piston that moves through the housing when the shock is compressed or extended from a rest position. When the piston receives a shock, it compresses the hydraulic fluid which then goes through a nozzle and impact as a jet on the vane of the impeller mounted on the shaft of a DC motor. From DC motor direct electric energy is found. In this project maximum 0.35V was found. Using impeller mostly reduces the voltage generation limit. Whereas, using a hydraulic motor could be more effective for voltage generation because the hydraulic motor has safe sealing. But in this project local weak sealing process is used which does not last long. Another problem is, here the fluid strikes on the impeller straight but if it strikes tangentially that would be more beneficial.The construction work in this project is done with locally available instruments and materials. The output is not good enough. But further work on this concept could lead to more energy saving in the automobile sector.*

Keywords: Shock absorber, DC motor, Impeller, Damper Oil.

1. INTRODUCTION

Energy in conventional shock absorbers gets dissipated as heat, and is not used in any way, which essentially a wastage in the perspective of the present crisis of energy throughout the world. Regenerative shock absorbers provide a means of recovering the energy dissipated in shock absorber. At present, automobiles and trucks have traditional shock absorbers to damp out the vibrations experienced due to the roughness of the roads. A regenerative shock absorber, however, converts parasitic intermittent linear motion and vibration into useful energy, such as electricity, and is the future of suspension technology for the global automotive industry.

Only 10-16 percent of the fuel energy is used to drive the car during everyday usage (Lei and co-workers, 2010 [1]) to overcome the resistance from road friction and air drag and actually transport the vehicle forward, which reflecting a lot of energy being wasted every day. Hybrid cars recapture some of the energy usually lost in braking but the dissipation of vibration energy by shock absorbers in the vehicle suspension remains an untapped source of potential energy. To harvest this lost energy, since 1986 to now on many researchers tried to design and construct the shock absorber which can be retrofitted to cars to convert the kinetic energy of suspension vibration between the wheels and sprung mass into useful electrical power. A proof-of-concept study is carried out in the project to evaluate the feasibility of obtaining significant energy savings by using optimized regenerative magnetic and hydraulic shock absorber in vehicles. In addition to other potential applications, the use of such shock absorbers might allow for improved energy efficiency in vehicles through the conversion of otherwise parasitic mechanical power losses into stored electrical energy, thereby leading to long distances between battery recharges. A regenerative shock absorber is capable of converting parasitic displacement motion and vibrations encountered under normal urban driving conditions to a useful electrical energy for powering vehicles and accessories or charging batteries in electric and fossil fuel powered vehicles.

Using lost energy in shock absorber may provide more power saving to the automobile sector. So, the regenerative shock absorber is an important concern for power saving and efficient energy saving in the automobile sector.

2. OBJECTIVES

I. To study of energy recovery in vehicle by using regenerative shock absorber.
II. To design a regenerative shock absorber.
III. To construct a regenerative shock absorber.
IV. To test the performance of the constructed regenerative shock absorber.

3. CONVENTIONAL SHOCK ABSORBER

The primary purpose of the shock absorber is to control spring and suspension movement. This is accomplished by turning the kinetic energy of suspension movement into thermal energy, or heat energy, to be dissipated through the hydraulic fluid.

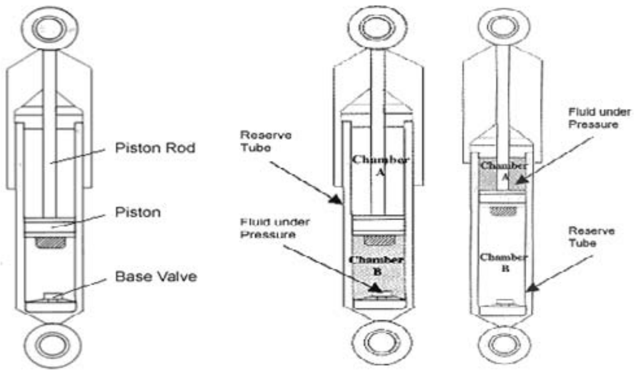

Fig.1: Compression and extension cycle

Shock absorbers are basically oil pumps. A piston is attached to the end of the piston rod and works against hydraulic fluid in the pressure tube. As the suspension travels up and down, the hydraulic fluid is forced through tiny holes, called orifices, inside the piston. However, these orifices let only a small amount of fluid through the piston. This slows down the piston, which in turn slows down spring and suspension movement.

Shock absorbers work on the principle of fluid displacement on both the compression and extension cycle as seen in the figure 1. A typical car or light truck will have more resistance during its extension cycle than its compression cycle.

4. REGENERATIVE SHOCK ABSORBER

A regenerative shock absorber is a type of shock absorber that converts parasitic intermittent linear motion and vibration into useful energy, such as electricity. Conventional shock absorbers simply dissipate this energy as heat.

When used in an electric vehicle or hybrid electric vehicle the electricity generated by the shock absorber can be diverted to its Powertrain to increase battery life. In non-electric vehicles the electricity can be used to power accessories such as air conditioning. Several different systems have been developed recently, though they are still in stages of development and not installed on production vehicles.

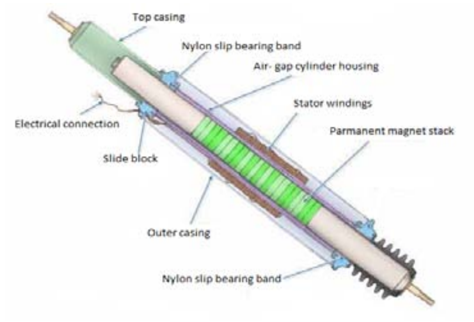

Fig.2: Regenerative electromagnetic shock absorber

5. DESIGNS & CONSTRUCTIONS

5.1 DESIGN CONSIDERATION

i. The piston material is selected AISI 1040 (Medium carbon steel).Because of good Machineability, good toughness and ductility, extremely popular and have numerous applications, responds to heat treatment , fair formability. [15]
ii. Yield strength of AISI 1040 , $\sigma_t =$353.4MPa[15]
iii. Modulus of elasticity of AISI 1040 =200 GPa[15]
iv. Cylinder burst only along longitudinal section because transverse stress is twice of the longitudinal stress
v. Outer cylinder is taken 1018 Mild (Low carbon) steel Because of its price is relatively low. Low carbon steel also possesses good formability. Low carbon steel has some of the best weldeability of any metal. [16]
vi. Yield strength of 1018 mild steel , $\sigma_t =$370.24Mpa [16]
vii. Inner cylinder material may be taken 1018 Mild (low carbon) steel
viii. Factor of safety for Yield strength N=5-7 [14] [shock load]
ix. Diameter of the piston head= 32.7 mm
x. Diameter of the piston rod= 22 mm
xi. Thickness of the piston head= 25 mm
xii. Length of the piston rod= 380 mm
xiii. Inner diameter of the inner cylinder= 32.00 mm
xiv. Outer diameter of the inner cylinder= 34.5 mm
xv. Inner diameter of the outer cylinder= 49.2 mm
xvi. Outer diameter of the outer cylinder= 50.7 mm
xvii. Diameter of the piston head= 32.7 mm
xviii. Diameter of the piston rod= 22 mm
xix. Thickness of the piston head= 25 mm
xx. Seat diameter =19 mm
xxi. Seat thickness =3 mm
xxii. Seat hole diameter =2 mm
xxiii. Valve diameter=19 mm
xxiv. Valve thickness= 0.20 mm

Existing Shock Absorber dimensions of Toyota Carena car are taken as reference.

5.1.1 Pressure Calculation (Piston):

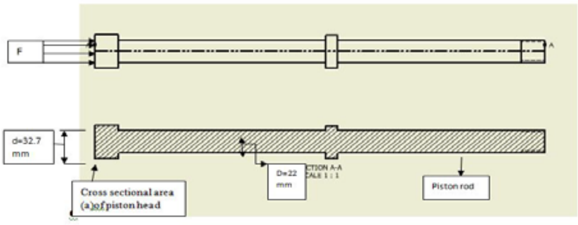

Fig.3: Cross-sectional view of the piston used

Force on Piston top, F=Pressure × Cross sectional area of piston head (a)

Or, F = P×a

Now, Area $a = \pi d^2/4$

Or, $a = \pi 0.0327^2/4$

Or, a=8.39×$10^{-4} m^3$

Because of shock load, factor safety is N=5

For design criteria, $\sigma_t = \frac{F}{A}$ × N

Or, A= $\frac{F \times N}{\sigma_t}$

Again Piston rod area A= $\pi D^2/4$

For design criteria, $\sigma_t = \frac{F}{A}$ × N

F=$\frac{\sigma_t \times A}{N}$

D=Diameter of the piston rod

A=$\frac{\pi}{4} \times D^2$ = $\frac{\pi}{4}$×(.022)^2=3.80$\times 10^{-4} m^2$

F=$\frac{353.3 \times 10^6 \times 3.80 \times 10^{-4}}{5}$ = 19179.14N

a=$\frac{\pi}{4} \times d^2$=8.398$\times$ 10^{-4}

So, Pressure, P=$\frac{19179.14}{8.398 \times 10^{-4}}$= 22.83MPa

Maximum pressure developed in the piston rod is 22.83MPa.So it can be said survival pressure of the piston rod is 22.83 MPa.

5.1.2 Critical Load Calculation for Piston Rod:

Maximum flexure stress in any section is given by,

σ = $\frac{Mc}{I}$

Here $\frac{I}{c}$ is called the section modulus and denoted by S, M is called the bending moment. So the variation of flexure formula is,

$\sigma = \frac{M}{S}$

For solid circle S= $\frac{\pi \times D^3}{32}$

σ = $\frac{M \times 32}{\pi \times D^3}$

So bending moment of the piston rod,

M= $\frac{\pi \times D^3}{32} \times \sigma$

M= $\frac{\pi \times 353.4 \times 10^6 \times 0.022^3}{32}$ N-m

M=369.43 N-m

Hooke's Law:

δ = $\frac{\sigma \times L}{E}$

Here, δ indicates total deformation, L is the length of piston rod, E is the modulus of elasticity.

δ = $\frac{353.4 \times 0.4}{20 \times 10^4}$ = 0.7068 mm

Now the Bending moment,

M=$P_{cr} \times$ δ

Here P_{cr} is the critical load required to maintain the rod in its deflected position without any side thrust.

$P_{cr} = \frac{M}{\delta}$

P_{cr} =$\frac{369.43}{0.0007}$ =5.22$\times 10^5$ N

This is the maximum axial load to which piston rod will be remain straight. Maximum pressure can be developed in the piston rod is 22.83MPa.For this pressure, the load which is developed lower than the critical load.

5.1.3 Pressure Calculation of Outer Cylinder:

Thickness of cylinder wall t_1=5.2mm

Now bursting force F_1=Pressure × Projection area

Or, F_1=Pressure × Diameter × Length

Or, F_1= P×D_1×L

Again Resisting force, R_1=Stress × Area

Or, R_1=σ_t× $t_1 \times L$

According to design criteria

Resisting force = Bursting force × Factor of safety

Or , R_1=F_1×N

Or, σ_t× $t_1 \times l$= $2P_1 D_1$N l

Outer cylinder diameter , $D_1 = 50.7$ mm

Design criteria, $\sigma_t t_1 l$ =$2P_1 D_1$N l

So, Pressure,

P_1 =$\frac{\sigma_c t_1}{2N D_1}$= $\frac{5.2 \times 370.248 \times 10^6}{0.0507 \times 7 \times 2}$ =25.12MPa

Maximum pressure developed in the Outer cylinder is 25.12MPa.So it can be said survival pressure of the piston rod is 25.12 MPa

5.1.4 Pressure Calculation of Inner Cylinder:

Cylinder wall thickness, t_2=2.5mm

Diameter, $D_2 = 34.5$mm

Now according to design criteria

Resisting force=bursting force ×factor safety

Or, R=F×N

Or, $\sigma_t t_2 l$ =$2P_2 D_2$N l

Or, $P_2 = \frac{0.0025 \times 370.248 \times 10^6}{0.0345 \times 5 \times 2}$ = 26.82MPa

Maximum pressure developed in the inner Cylinder is 26.82MPa.So it can be said survival pressure of the piston rod is 26.82 MPa.

5.2 Construction Process:

5.2.1 DC motor and impeller insertion:

A hydraulic motor is a mechanical actuator that converts hydraulic pressure and flow into torque and angular displacement (rotation). The hydraulic motor is the rotary counterpart of the hydraulic cylinder. Because of unavailability of hydraulic motor an impeller is used for this purpose. Impeller is mounted on the shaft of DC motor where fluid is struck coming from a nozzle. This impeller is made by considering the area available in shock absorber. Positioning of the impeller is made carefully where fluid strikes impeller straight. After rotating the shaft of DC motor, voltage is developed.

Specification of DC motor used:
RF-300EA-12350
KD41012014
D/V 5.9

Construction of the compartment for impeller including valve and seat:

The compartment **(**Fig.4) which is attached to the inner cylinder includes in accordance with nozzle, seat with four holes, four relief valves and spring. Relief valve and seat is supported by a spring. During the compression stroke or downward movement of the piston, some fluid flows through the nozzle. Then spring is compressed. For this, it is easy to pass fluid through seat and valve accordingly. During the extension stroke, the spring is extended. For this, it is difficult for fluid to pass through the valve and seat. This is how, vibration energy is dampened.

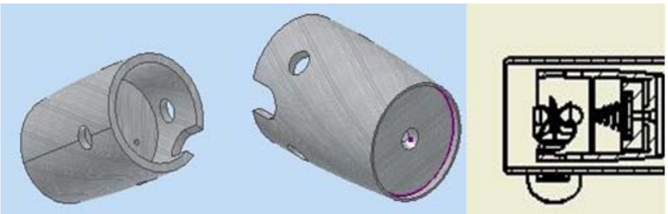

Fig.4: the compartment which is attached to the inner cylinder

Dimensions (mm) of the compartment:

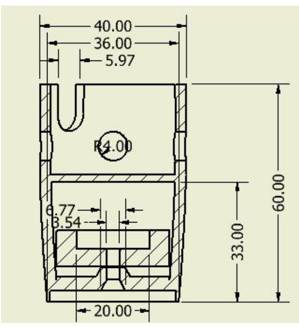

Fig.5: Compartment attached to the inner cylinder

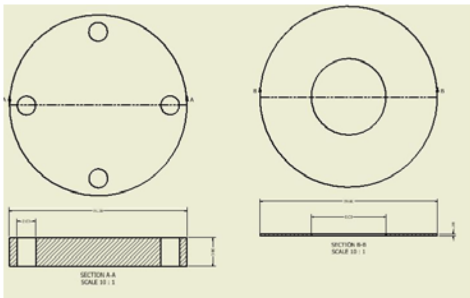

Fig.6: Seat and Valve

Dimension of the seat and valve area,
Seat diameter =19 mm
Seat thickness =3 mm
Seat hole diameter =2 mm
Valve diameter=19 mm
Valve thickness= 0.20 mm

5.2.2 Sealing:

Silicone rubber is a rubber-like material composed of silicone, itself a polymer, containing silicon together with carbon, hydrogen, and oxygen. Silicone rubbers are widely used in the industry, and there are multiple formulations. Silicone rubbers are often one- or two-part polymers, and may contain fillers to improve properties or reduce cost. Silicone rubber is generally non-reactive, stable, and resistant to extreme environments and temperatures from -55°C to +300°C while still maintaining its useful properties. Due to these properties and its ease of manufacturing and shaping, silicone rubber can be found in a wide variety of products, including: automotive applications; cooking, baking, and food storage products; apparel such as undergarments, sportswear, and footwear; electronics; medical devices and implants; and in home repair and hardware with products such as silicone sealants

For sealing Hi-temp RTV Silicone Gasket Maker (red) is used.

It forms to any shape instantly and cures fast. After curing, it resists cracking, shrinking and migration caused by thermal cycling. It can also work up to 260°C (500°F) and of good resistance of oil, water, and anti-freeze and transmission fluid. It's widely used to seal timing chain covers and various other covers.

5.2.3 Oil Selection:

Damper oil is usually a selected light mineral oil, sometimes instead a synthetic oil which is more but which may have reduced variation of viscosity with temperature. The usual damper mineral oil contains sulphur compounds, giving it a lingering (Remain present although waning or gradually dying) noxious (physically) smell.

ATF DEXRON II D oil is preferred to use for this shock absorber.

This oil has a high viscosity index for automatic transmissions. It is characterized be a high chemical stability, increased anti-wear properties and an excellent resistance against ageing.

5.2.4 Assembly of the Components:

Figure: 7 Shows 3D assembled view of the constructed regenerative shock absorber. A regenerative hydraulic shock absorber includes a shock housing that has a compressed volume and an extensive volume. A piston is disposed in the shock housing. In a first mode the piston moves through at least a portion of a compression stroke to pressurize hydraulic fluid in the compression volume. In a second mode the piston moves at least partially through an extended stroke to pressurize hydraulic fluid in the extensive volume. The compartment which is attached to the inner cylinder includes in accordance with nozzle, seat with four holes, four relief valves and spring. Relief valve and seat is supported by a spring. During the compression stroke or downward movement of the piston, some fluid flows through the nozzle. Then spring is compressed. For this, it is easy to pass fluid through seat and valve accordingly. During the extension stroke, the spring is extended. For this, it is difficult for fluid to pass through the valve and seat.

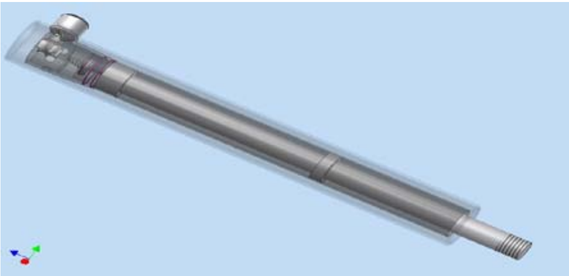

Fig.7: 3D assembled view of the constructed regenerative shock absorber

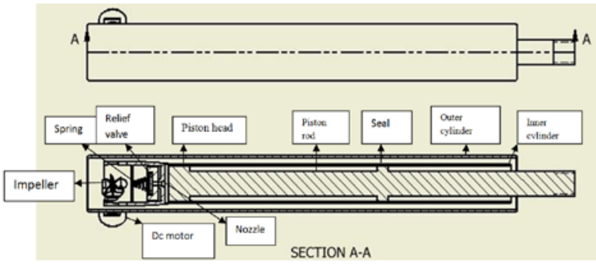

Fig.8: 2D assembled views of the constructed regenerative shock absorber

5.3 Different components of Regenerative Shock absorber:

Fig.9: DC motor coupled with impeller

Fig.10: Cylinder

Fig.11: Compartment for impeller

Fig.12: Bearing

6. RESULTS AND DISCUSSIONS

To improve vehicle fuel economy by harvesting the untapped source of potential energy, the concept of energy recovery by regenerative shock absorber has developed. For the design and construction of the regenerative shock absorber some fundamental concepts and necessary feasibility about this development with information are studied carefully which is about early inventions concerning this concept. The dimensions are maintained with very similar to existing one. The local availabilities of the necessary equipments are checked. The Tiny Hydraulic motor is needed for the experiment. Because of unavailability of hydraulic motor, an impeller is used for this purpose. Impeller is mounted on the shaft of DC motor where fluid is struck coming from a nozzle. This tiny impeller is made by considering the area available in shock absorber. Positioning of the impeller is made carefully where fluid strikes vane straight. The compartment which is attached to the inner cylinder includes nozzle, seat with 4 holes, relief valves and spring. After this, testing was made. At first a single press in the piston rod with hand was given and the voltage was developed 0.03 V. Afterwards, No power has found. Because of hydraulic oil was choked. There was a problem of hydraulic oil to pass through the outer cylinder to the inner cylinder. That is why; construction was changed to passing fluid through the outer cylinder to the inner cylinder. Then voltage was developed for several times. These voltages are given in Table 1 from observation 1-4.

Table 1: Experimental data

Observations	Voltage
1	0.04V
2	0.03V
3	0.02V
4	0.01V
5	0.9mV
6	0.5mV
7	0.5mV
8	0.4mV
9	0.3mV
10	0.2mV
11	0.2mV
12	0.1mV
13	0.35V

From the observation it can be said that there was still the problem of hydraulic oil to pass through the outer cylinder to the inner cylinder. Leaking is a severe problem in this construction. First oil was filled after sealing. Then another way is tried. After sealing, it was kept without filling oil for one day. Then the oil is filled. Then voltage was developed for several times. These voltages are given in Table 1 from observation 5-12. Then again another way is tried. At first only inner cylinder was filled with hydraulic fluid. Then it was pressurized by the piston. A single press in the piston rod with hand was given and the voltage was developed 0.35 V (Table 1, observation 13). So, more power can be developed if sufficient hydraulic oil passes through the outer cylinder to the inner cylinder. As fluid strikes impeller straight, efficient impact is not occurring. It will be more efficient if fluid strikes impeller tangentially. Due to unavailability of shape magnet the construction of hydro-electromagnetic shock absorber is not made. In future, it may be possible if shaped magnet is available.

7. CONCLUSION

This thesis project is categorized for the innovation of a new technology, a regenerative shock absorber. Regenerative shock absorber has been already a known concept now-a-days. Here, in this project a regenerative hydraulic shock absorber is designed and constructed. The voltage developed in this regenerative shock absorber is not satisfactory. More voltage could be found if further work has done.

7. REFERENCES

[1] Lei Zuo, Brian Scully, Jurgen Shestani, and Yu Zhou. “ Design and characterization of an electromagnetic energy harvester for vehicles suspensions.” Smart Material Structure 19 (2010) 045003(10pp)

[2] John C. Dixon “The Shock Absorber Handbook” (2nd Edition), 2007.

[3] Browne, A.L., Hamburg, J.A.: On-road measurement of the energy dissipated in automotive shock absorbers, Symposium on Simulation and Control of Ground. Vehicles Transport. Syst. 2, 167–186 (1986).

[4] Karnopp, D.: Permanent magnet linear motors used as variable mechanical dampers for vehicle suspensions. Vehicle System Dynamics 18, 187–200 (1989).

[5] Fodor, M.G., Redfield, R.: The variable linear transmissions for regenerative damping in vehicle suspension control. Vehicle Syst. Dyn. 22, 1–20 (1993).

[6] Suda, Y., Shiba, T.: New hybrid suspension system with active control and energy regeneration. Vehicle Syst. Dyn. Suppl. 25, 641–654 (1996).

[7] Graves, K.E., Iovenitti, P.G., Toncich, D.: Electromagnetic regenerative damping in vehicle suspension systems. Int. J. Vehicle Designs 24(2/3), 182–197(2000).

[8] Goldner, R.B., Zerigian, P., Hull, J.R.: A preliminary study of energy recovery in vehicles by using regenerative magnetic shock absorbers, Paper SAE 2001-01-2071, SAE/ DOE Government/Industry Meeting, Washington, DC, May 14–16 (2001).

[9] Abhijit Gupta, J.A .Jendrzejczyk, T.M.Mulcahy and J.R.Hull “Design of Electromagnetic Shock Absorbers”; Springer Science+Business Media B.V. 2007; published online: 22 May 2007.

[10] Rani, S.: Bose breakthrough: electromagnetic auto suspension. Siliconeer, January (2005).

[11] Goldner, et al. “Electromagnetic linear generator and shock absorber”; US Patent No. 6,952,060.

[12] "Vehicle shock absorber recovers energy from bumps in the road." http://www.physorg.com/news188035494.html.

[13] "More power from bumps in the road: Energy-harvesting shock absorbers." http://www.physorg.com/news153505357.html.

[14] FairesVirgil Moring,Design of Machine elements;The Macmillan Company ,United States of America; Edition earlier,1965;page 20.

[15] www.OnlineMetals.com.