International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

Conceptual Design of Electromagnetic Damper for Motorcycle Suspension System

Elankovan M. G .
Final Year,
Department of Mechanical Engineering
Thanthai Periyar Govt. Institute of Technology,
Vellore, Tamil Nadu, India

Dr. Sai Ramesh A.*
Assistant Professor,
Department of Biotechnology
Sree Sastha Institute of Engg. and Tech., (SSIET)
Chennai - 600123, Tamil Nadu, India

***Abstract* - The function of a suspension in any vehicle is to prevent shock during rough road conditions and to enhance traction force between road surfaces. Conventional suspension system includes a spring and shock absorber. Any notable invention when taken into account, it can be perceived that it has evolved greatly to reach such height by addressing their limitations. This study tries to exploit the suspension systems since its usage right after the invention of IC engines and evolution till their present dimensions. Typical dampers on continuous usage loses its efficiency due dissipation of energy into heat which increases the temperature of the viscous oil eventually making it thinner. Many advancement including mono-shock suspension increased suspension quality in motorcycles. Nevertheless, the latter has a huge disadvantage in implementing it on running vehicles that employed dual swing arm rear suspension, as chassis needs redesigning. An alternative damper design which employs electromagnets that has several advantages overcoming the limitations of commercial oil dampers is suggested. So, a new model is proposed which can be employed in replacement for oil viscous dampers that has application in machineries and automobile. This concept of using electromagnet in which magnetic field can be controlled electronically makes the overall suspension to be semi-active, and possibility of energy harvesting. The components involved in this design include a highly conducting solenoid coil which is concentrically placed with permanent cylindrical Alnico magnet. Based on Faraday's induction law viscous damping is achieved and holds advantages over other shock absorbers making it reliable and stabile.**

Keywords-Eddy Current Damper; Viscous Damping; Semi-active Suspensions; Electromagnetic induction.

I. INTRODUCTION

Development can be traced back since the first modern suspension used in Ford Model T hit a commercial success [1]. They were mainly a symbol of luxury those days now turning out to be an essential for optimized performance. Suspension has become one of the key elements of modern motorcycles as safety and comfort are influenced by it. In this paper various suspension systems that have been used in motorbikes were studied and discussed briefly. Suspension systems have direct responsibility of safety during anti-squat and anti-dive. What happens when you hit a huge bump of speed barker at 60kmph, eventually it will lead to an accident if there was no suspension system rather leading to a severe vibration, Moreover when you apply a brake on front wheel some part of braking force gets used up by front suspension, when maximum energy is absorbed by the front suspension and the remaining excess breaking force it will lead to pivoting about the point of contact of the front wheel. And similarly effect is observed during acceleration. Hence suspension systems are of great importance to vehicles handling and braking, and to providing better traction, safety and comfort. In this article a new theoretical design of electromagnetic damper for general applications were discussed and a simple concept model was designed using CATIA V5 for a typical dual swing arm rear suspension of motorcycle with feedback system and electronic control unit is proposed. Turing out passive suspension into a semi-active one.

II. REVIEW ON SUSPENSION

Suspension aims to isolate the *sprung mass* [2] in ideal position. Suspension system aims to keep the centre of mass to travel in a straight line. Front wheel and rear wheel both have suspension system individually. Suspension *Travel & sag* are the tuning parameters taken into account while designing; *Preload* is the load applied to the system that prevents topping up and as well as bottoming. *Bottoming* is when a suspension deflects to its maximum travel and no more compression of spring takes place leading to dive. Spring and damper make a part of suspensions *rebounce damping and compression damping*[3], when the wheel hits the bumps bike experiences vertical acceleration and force acts on suspension system makes the spring to compress by storing some energy, and damper controls the weave of sprung mass by spring's oscillation, here part of energy stored is dissipated in form of heat by the damper. More the heat released by the damper, good it works.

A. Active and Passive suspension system

Most generally almost majority of motorbikes in India have passive suspension system. BMW in 2012 was the first to introduce semi-active suspension in its HP4[1] model with dynamic damping control(DDC) which uses variety of sensors to determine the conditions and riding scenario and changed compression and rebound damping to suit those conditions it uses electronically controlled valves that allow those damping changes to be made in milliseconds. These can push the wheel down into a dip in the road or shrink it over a bump whereas semi-active system still rely on the road and the spring physically.

B. Types of springs used

Typical motorbike telescopic fork consists of single rated spring connected in parallel with air spring[5]; Bottom of the air spring has fork oil. Amount of fork oil has direct effect on controlling the suspension. Single rated springs, Single coil dual rated spring, progressive rated springs are used. Air spring is a type of progressive rated spring i.e. it requires less load to compress initially and to make further displacement of spring higher load are required and the preferable where huge sprung mass is desired as in case of busses, not suiting for motorbike rear suspension.

C. Various damping techniques

Pneumatic and hydraulic shock absorbers are commonly known which are cylindrical in shape and has a sliding piston inside. The fluid filled piston/cylinder combination is a dashpot or damper. Some dampers uses magneto-rheological (MR) fluid instead of viscous oil which has suspended magnetic particles in it which responds to external magnetic field when applied[4], On the other hand this technology is new and still in developmental stages. Typical damper has a major drawback, when used continuously viscous oil becomes thinner and it is impossible to have tiny damping. *A good damper is one which is softer on small bumps and becomes stiffer and stiffer on harsh bumps.*

III. FRONT AND REAR SUSPENSION

First cycle powered by motor has no suspension at its rear are referred as *Hardtails[1]*, as some part of pedalling energy is wasted as heat in suspension it was not used. Known type of front suspension was telescopic oil damped front suspension, leading link fork, Earles fork, Grinder fork, Telelever and Duolever; But the sustained suspension was the one with little modified telescopic fork.

Mono-shock suspension system is greatly famous now days. It has evolved due to various limitations of rear suspension systems being currently used. Even though front suspension system was globally accepted before World War I several manufacturers did not use rear suspension, later they adopted notable systems used were Indian Single swing arm suspended from leaf spring type; Plunger suspension type and swing arm which are widely used now a days also.

A. Limitations of typical rear suspension in bike

Most of the Indian bikes uses dual swing arm suspension system which pivots, it consists of progressive rated springs of single coil or single coil dual rated spring or two different rated spring one inside the other placed concentrically. Dampers consists cylinder with a piston rod which is filled with viscous fluid which opposed the motion of piston [5]. Absorbed energy is released mostly as heat energy to the surrounding eventually heating up the thick fluid inside the damper. Damper oils with specific ISO standards are used for certain application. In addition to providing a lubricating and cooling bath for the dampers and bushings of the fork and shock to function in, the suspension fluid is the medium that is used to provide damping in a modern system.

Essentially, the oil is forced through an orifice or past a spring loaded shim to creating a resistive force to the action of the shocks. Aside from other changes that effect damping, the viscosity of the oil and heating up of the oil (as the viscosity reduces as the oil heats up) will be large limitation factors in this system, some low grade oils even foams up. *Quality of suspension system is drastically reduced on continuous usage over time.* Riding on rough road surfaces leads to such problems, however on riding on smooth surface will maintains its quality.

B. Need for the alternative design

In order to overcome limitations found in *Twinshock swing arm suspensions* alternative ideas were studied and thus *Monoshock swingarm suspension[3]* systems were developed for providing better ride quality and succeeded, that become widely popular. It is not possible for bikes using dual swing arm suspension to adapt Monoshock suspension as the chassis need a modification which makes us impossible to upgrade.

C. Mono-shock and ECD suspension system

Better damping is achieved, stiffer spring is used, in case of dual shock both the spring damper system placed to left and right of the rider should sync as a single system such no problems were not faced as it has only one spring dashpot set. *As the centre of mass lines in vertical axis closer to suspension system, an excellent comfort with safety was achieved.*

Due to high compression and rebounce damping rate of eddy current dampers, it was widely used in machineries to absorb shocks [11]. A normal eddy current damper (ECD) consists of cylindrical non-magnetic hollow metal rod which is concentrically placed inside the powerful bar magnets. Eddy currents are induced in circular fashion by induction, eventually dissipating heat in form of eddy current loss.

IV. ELECTROMAGNETIC DAMPER

Alternative idea to overcome limitations of *Twin shock suspension system* is given theoretically which has a modified electromagnetic damper. Eddy current dampers are highly effective in comparison with electromagnetic damper [11], the major drawback is that damping in case of ECD cannot be controlled effectively as the current loops are created inside the solid section of the cylinder [7]. This led to use the solenoid which is compactly wound whose coil is insulated and serves the purpose of electromagnet as well. It consists of many layers which has feedback coil whose ends are connected to the electronic controller achieving semi-active suspension system.

A. Introduction to electromagnetic damping

When a magnetic bar is inserted into a cylindrical coil (solenoid) electromagnetic flux is induced in the coil, according to *Faraday's induction principle [7]*. Induced emf induces current in the coil by which solenoid creates an opposing magnetic field which opposes the motion of cylindrical bar magnet placed concentrically, which is in accordance with Lenz law[7]. Small force is required to make small displacement of bar magnet and large force is required to make large displacement which increases progressively not linearly thus using this concept damper similar to viscous damping is achieved [5]. When some additional current is passed through the coil grater magnetic field is developed and grater opposing force is created, active suspension control is achieved.

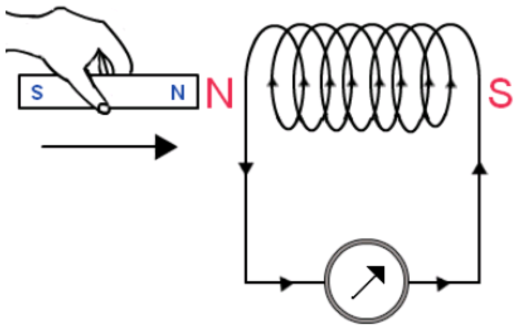


Fig. IV (a) Illustrating Faradays law of Induction

Induced emf in the coil is given by $-\frac{\partial \phi_B}{\partial t}\ Volts$

B. Energy balance equation

A typical dual swing arm rear suspension was the focused. Consider a suspension system, which has a single rated open coil spring of stiffness $k\ N/mm$ and the maximum working strobe of suspension to be $\delta_{max}\ mm$. For a maximum suspension travel δ, considering 75% of total working strobe [10]

$$0.75\ \delta_{max} = \delta$$

Maximum energy change that a suspension spring can store form its initial payload condition (*sprung mass)* to final suspension travel is given by

$$\Delta E_s = -k \times \delta^2$$

This would be the maximum energy $|\Delta E_s|$ condition needed by the electromagnetic damper to be absorbed

Consider a closely would multilayer solenoid which has Number of turns N that has a coil resistivity of $R\ \Omega$ and cross-sectional area of A placed concentrically inside a circular bar magnet of strength B_e

At the time when spring compresses the circular bar magnet enters the solenoid which induced the emf ε by change in the flux$\varphi_B\ \ T/m^2$. Emf induced in the solenoid coil by the magnetic field B_e of cylindrical bar magnet is given by [7]

$$\varepsilon = -\frac{d\varphi_B}{dt}$$

Where φ_B is given by the surface integral

$$\varphi_B = \iint \vec{B}.\overrightarrow{dA}$$

This induced emf produces an induced current of i, now the magnetic field B_c produced by the current i, in the solenoid is given by

$$B_c = \mu_o \mu_r \frac{Ni}{l}$$

Where μ_o is the permeability of free space, μ_r is the relative permeability in which solenoid is placed, in this case cylindrical bar magnet. And l is the loop circumference

$$\varphi_B = B\ .A$$

$$\varphi_B = \frac{\mu NA}{l} i$$

$$\varepsilon = -\frac{d}{dt}\left(\frac{\mu NA}{l} i\right)$$

$$|\varepsilon| = \frac{\mu NA}{l}\left(\frac{di}{dt}\right)$$

If R is the resistor of the coil then energy dissipated is given by V^2/R in this case V is analogues to emf induced in the solenoid $|\varepsilon|$

Hence, heat dissipation is given by

$$E_c = \frac{|\varepsilon|^2}{R}$$

$$E_c = \frac{1}{R}\left(\frac{\mu NA}{l}\right)^2 \left(\frac{di}{dt}\right)^2$$

Now by energy conservation principle

$$E = |\Delta E_s| = E_c$$

$$|\Delta E_s| = \frac{1}{R}\left(\frac{\mu NA}{l}\right)^2 \left(\frac{di}{dt}\right)^2$$

This equation clearly shows that induced current changes with respect to time, hence energy dissipated is a function induced current and time $E(i,t)$

The force of opposing electromagnetic field with respect to cylindrical bar magnet, which is repulsive in nature is given by *Gilbert's law*[8][9]

$$F = \frac{B^2 A}{2\mu}$$

Where B is the net magnetic field by cylindrical bar magnet and the solenoid

$$B = B_e + B_c$$

$$F = \frac{(B_e + B_c)^2 A_{cs}}{2\mu}$$

Where area A_{cs} is the common curved surface area between the cylindrical surfaces in contact

Under the no application of external field current I, the induced magnetic field in the solenoid is same as bar magnet, hence repulsive force under no application of external current I is

$$F = \frac{(2B_e)^2 A}{2\mu}$$

- This is the smooth riding condition, which do not require any adjustment to suspension system

This force is also a function of external field current I and time t

$$F = F(i, t)$$

$$I = I(i, t)$$

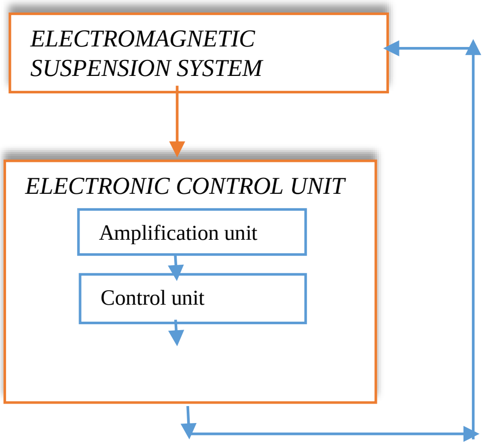
Comparing the above two equations repulsive force is the function of current rate I

$$F = \frac{d}{dt}(I)$$

A small variation in the external field current applied to the solenoid will change the force that needs to be exerted by the damper

C. Electronic control unit (ECU)

By controlling the field current rate $\dot{I}$ with the help of electronic controlling system specially designed the force F can be varied within maximum to minimum range controlling the overall suspension to enhance during bumps, pot holes and irregularities.



D. Conceptual Model of Proposed Damper
The shown below in the fig. IV.*(b)* looks similar to that of a normal suspension used in motorcycles at the rear has a highly modified electromagnetic damper. It has three sets of solenoid alnico magnet combination concentrically placed inside.

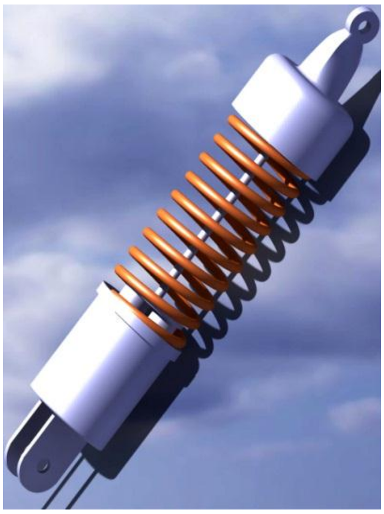


Fig. IV. (b) Assembled view of proposed spring-damper system modelled in CATIA V5

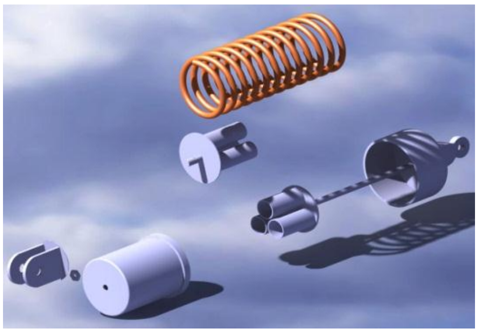


Fig. IV. (c) Shows the exploded view of designed system.

E. Solenoid and feedback coil
Many layers of solenoid is wound which has several number of turns each. One layer of solenoid serves the purpose of feedback to the ECU which clearly depicts the road scenario to the controller in order to receive the optimum external field current that is passes through the active electromagnetic coil. Based on the feedback given suspension system is made semi-active type enhancing the overall suspension quality of the motorcycle.

Process

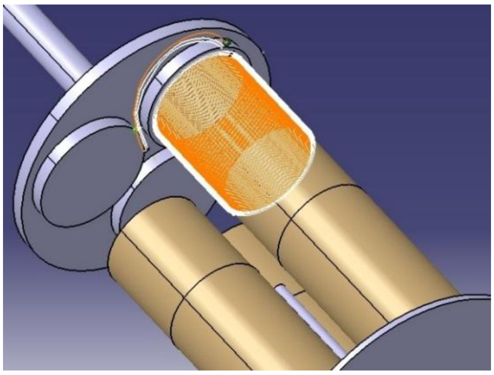


Fig. IV. *(d) Depicts the zoomed view of solenoid magnet with active turns (white) and feedback coil.*

Fig IV. (e) Shown describes maximum load condition with full suspension travel

V. ADVANTAGES OF ELECTROMAGNETIC DAMPER BASED SUSPENSIONS SYSTEM

1. Better consistent handling and braking.
2. In ordinary dual shock swing arm system both of them needs to work simultaneously as a single system which does not happen due to poor maintenance, but this system is auto adjusted by electronic control unit.
3. Heat loss is less as no viscous oil is used, and a considerable of amount of energy can be harvested.
4. It provides semi-active suspension leading to enhance ride quality. Which is the major advantage of this system.
5. Adaptation of this system is chapter as compared to Mono-shock suspensions.
6. It is possible to upgrade this enhanced rear suspension system to bikes that are currently employed with traditional oil viscous dampers as the dimensions fits.
7. Usage of these dampers is limited not only to bikes but also in machine parts were vibrations are to be damped.

VI. CONCLUSION

The proposed model of electromagnetic damper based suspension system was designed based on theoretical perspective. No quantitative analysis were made, Work involved in this paper implies that these kinds of suspension dampers have more feasibilities of evolving in future suspension technology. In today's automobile world semi-active suspension are of major research importance. Some limitations faced in electromagnetic damper still needs to be researched and rectified.

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