REGENERATIVE SHOCK ABSORBER FOR HYBRID CARS

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Abstract

All vehicles use suspension system. The suspension system mainly consists of a mechanical spring and a damper. The damper dissipates the mechanical energy into heat and thus damps down the vehicle oscillations. In a bid to reduce the vehicle emissions, many technologies are being thought to reduce energy losses and also recover energy from the energy losses if any. One such technology is regenerative braking where the heat lost due to braking is being recovered, converted into electricity and the onboard batteries are charged. Similarly, in a shock absorber, the mechanical energy being converted into heat, instead of wasting this energy it can also be recovered as electricity and the onboard batteries can be charged. This concept of recovering energy in a shock absorber is known as regenerative shock absorber.

The objective of this project is to design a regenerative shock absorber which can harness the energy. In the present work, a regenerative shock absorber is modeled and analysed for emf generated using Ansoft Maxwell and a physical model was built to validate the model.

A regenerative shock absorber model with NdFeB magnet as core and three piston stacked generated 12 volts AC operated at a speed of 1 m/s and the physical built based on this computational model developed 2 volts when operated at the same speed but with steel as core. The difference emf generated is due to the steel core. Since the voltage generated is lower than battery charging voltage, newer concepts have to be thought of to increase the voltage levels.

Keywords: Torque, Regenerative shock absorber, Permanent Magnet, NdFeB, emf and Damper.

Nomenclature

A	Area of magnetic flux path, in m^2
AT	Total mmf, in A
B	Flux density, in Wb/m^2 (Tesla)
H	Magnetising force, in A/m
L	Length of magnetic path, in m
S	Reluctance, in A/Wb
Φ	Magnetic flux, in Wb
μ	Absolute permeability of the magnetic material, in H/m
μ0	Permeability of free space = 4π x 10-7 in H/m
μr	Relative permeability

Abbreviations

AC	Alternating Current
CAD	Computer Aided Design
DC	Direct Current
emf	electro motive force
mmf	magneto motive force
NdFeB	Neodymium Iron Boron
PM	Permanent Magnet

1. INTRODUCTION

All vehicles have suspension system. The suspension system has links, spring and damper. The suspension system helps in resisting squat, dive and roll. It also helps in reducing the amplitude of vibrations reaching to passengers. Due to suspension and vehicle mass system, the energy conversion happens from kinetic energy to potential energy and vice versa. In order to dampen the vehicle oscillations from this spring mass system dampers are used in vehicles. The spring takes the entire shock load while the damper dissipates the mechanical energy into heat energy and thus damps down the vehicle oscillations. The shock absorber also reduces the dynamic wheel load variations and prevents the wheels lifting from road surface and gives a better steering and braking control during dynamic conditions.

With depilating fossil fuel, increasing global warming and stringent government norms in developed and developing countries has resulted automotive original equipment manufacturers to think on an alternate option, as automobiles play an important role in all said things. At the same time demands from the automobile customer/end user is increasing day by day, so it becomes a big challenge for automobile original equipment manufacturer to address above requirements. Though there are alternate fuelled vehicles, newer technologies in automobiles, the automotive original equipment manufacturers still could not able find a break through with electric vehicle. These electric vehicles can almost address the above said problems in ease. But the problem with electric vehicle is that it requires frequent charging and failure to establish the charging infrastructure by original equipment manufacturers. Though there are some on board charging systems present in such vehicles, those systems has to rely on traction motor (or) battery for its functioning. In turn increasing load on the motor. Because of this various researchers, automobile original equipment manufacturer along with government agencies are working on various ways of harnessing energy in automobiles which are wasted whenever the vehicle is running.

Regenerative shock absorber is an electro mechanical device which converts the vertical movement of suspension i.e. kinetic energy of suspension into electrical energy. It is done by having a simple electrical system comprising of a current carrying conductor and magnetic field on the shock absorber. As per faraday's law, during operation either the magnetic field or conductor is made to move and other one kept as stationary. This makes the magnetic field to cut the conductor and there by induces an emf in the conductor. The generated electricity can then be used to charge the batteries apart from the existing regular charging mechanism present. This system can be more useful in electric, hybrid vehicles also in conventional cars which can reduce the load on the engine.

2. PROBLEM DEFINITION

An electric car usually needs a constant charging for better mileage. Even our conventional internal combustion engine cars use alternators to cater electrical energy requirement with in vehicle. An alternator is an electro-mechanical device coupled to engine, whenever engine starts alternator also starts functioning. There by charging the battery of the vehicle. Alternator usually works with an efficiency of around 50-60% [1]. With the global warming increasing year over year, emission norms for the automobiles could go further stringent in the years to come. Because of this scenario already automobile original equipment manufacturers are facing pressure to make more efficient vehicles. It can be done either by downsizing the engine (or) reducing the vehicle weight, etc. Engine downsizing can put pressure on other subsystems which relay on engine for their functioning, in other words other subsystems also needs to be downsized accordingly. But the requirement in cars for electrical energy has increased over years, which means a bigger alternator in conventional IC engine cars and in case of electric vehicle a better charging system. Figure 1 shows the trend in the current requirements over the years.

This has lead to inventing some energy recovery mechanism whenever vehicle is operated like regenerative braking. It actually generates electricity whenever brake is applied. Though it is commercialised it has got some limitation, it can only recover 15-20% [1] of the energy wasted during braking.

3. METHODOLOGY

- Literature review for shock absorber, linear generators and magnets were carried out from SAE papers, books, Journals, magazines and websites.
- Based on reviewed literature a system that converts kinetic energy of shock absorber to electrical energy was conceptualized.
- Designed system was retro-fit and it was integrated to existing shock absorbers.
- Preliminary electro-magnetic analysis was carried over out to understand the magnetic flux flow.
- Based on the generated magnetic flux different concepts were built.
- A detailed 2D analysis was carried out on the different concepts to determine the induced voltage using Ansoft Maxwell.
- A technology demonstrator/prototype was fabricated to exhibit the functionality using one of the concepts among various concepts.
- Prototype was tested / validated with the analysis results for generated voltage.

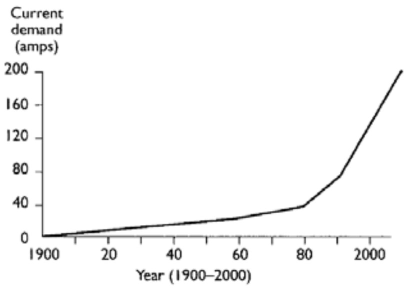

Fig. 1 Trend on current demand over years in car [1]

4. SIMULATION

FE model was created for two different concepts one with a single piston and other with stacks of three pistons. As shock absorber is symmetry an axi-symmetry model was create. Each concept was simulated for two different core materials and their results were studied. A shock absorber assembly finite element model comprising of inner tube, outer tube, piston, core and coil is depicted in the Figures 2 and 3.

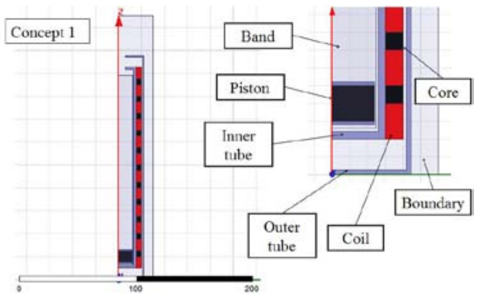

Fig. 2 Concept I finite element model

An air gap of 1 mm is maintained in between inner tube and pistons were maintained. There were totally 10 number of coils connected in series forms one single winding. Each coil was having 100 numbers of turns leading to total of 1000 numbers of turns. It can also be noticed from Figure 2 that each coil is separated with core.

A band was assigned comprising the piston, Maxwell understands that the components within band can move with specified velocity. Piston was made to move at a velocity 1 m/sec [2] which is the extreme conditions of shock absorber piston movement. A balloon boundary was created comprising of all the above components.

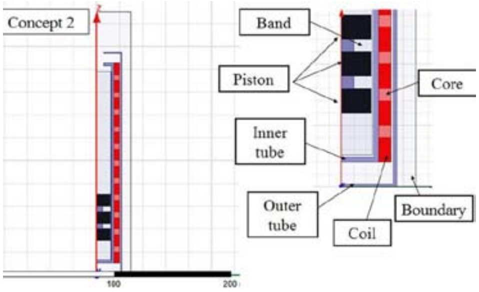

Fig. 3 Concept II finite element model

5. VALIDATION STUDIES

5.1 Validation setup

- A tube of ID 20.8 mm was machined to a wall thickness of 1.2 mm and a length of 213 mm. Dimensions of the tube were slightly different than that of inner tube of the shock absorber, main reason for this was non-availability of magnets to suit the dimensions of inner tube.
- Three permanent magnets of OD 19 mm, ID 6 mm and thickness of 10 mm were used as piston. Thickness of the permanent magnets was same as that of piston thickness.
- Pistons were then mounted on an OD 6mm rod. It forms a piston assembly.
- Steel rings of ID 23.2 mm, thickness of 5 mm and OD 33.2 mm was machined and press fitted into tube with a in between gap of 10 mm, totally ten such rings were fitted in tube.
- Magnetic wire of gauge SWG 33 was wound in the gap formed by the steel rings.
- Total of 1000 number of turns were wound the gaps i.e. 100 turns per each gap. All coils are connected in series.
- Whole piston assembly is the mounted on tube with the help of end bushes.
- This setup is then mounted on a crank and slider mechanism which was designed specifically to test the regenerative shock absorber.
- The test is conducted at 1 m/sec and at a stroke of 100 mm. then the results were recorded.

Fig. 4 Fabricated regenerative shock absorber

6. RESULTS AND DISCUSSION

Following chapter discusses the results of the two concepts and two different cases in each concept.

6.1 Concept I

6.1.1 Case I coil connected in series with NdFeB magnet as core

From the Figures 6 and 7 the maximum flux linkage around 0.126 Wb and maximum voltage is 11.5 V. This scenario is noticed because core and piston were of NdFeb permanent magnet. Core produces a static magnetic flux and it attracts the moving flux from piston. This can be clearly seen in Figure 5. So, at a given point more flux cuts the conductor there by inducing higher emf in conductor.

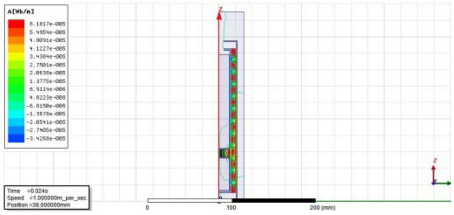

Fig. 5 Flux line plot for concept I, case I

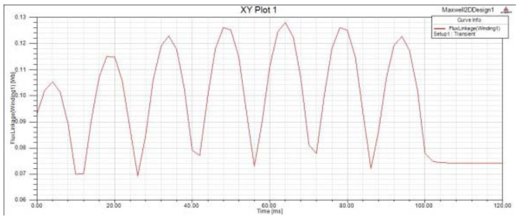

Fig. 6 Flux linkage plot for concept I, case I

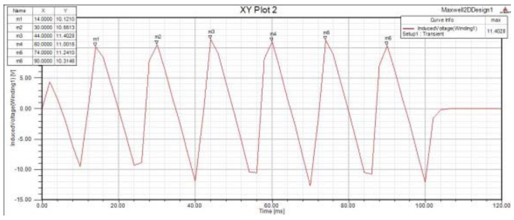

Fig. 7 Voltage plot for concept I, case I

6.1.2 Case II coil connected in series with steel as core

From the Figures 9 and 10 the maximum flux linkage around 0.045 Wb and maximum voltage is 1.6 V. In this case core is steel (steel 1010 from Maxwell material library) and piston is NdFeB permanent magnet. As compared to case I steel has got lesser permeability, it means core attracts lesser magnetic flux to pass through compared to the previous case. So there is a lesser flux cutting conductor at any given point of time and so less emf is induced in the conductor.

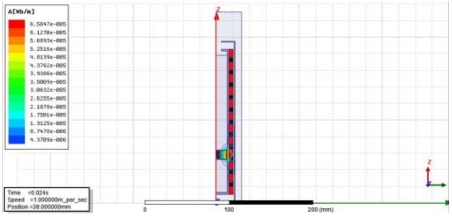

Fig. 8 Flux line plot for concept I, case II

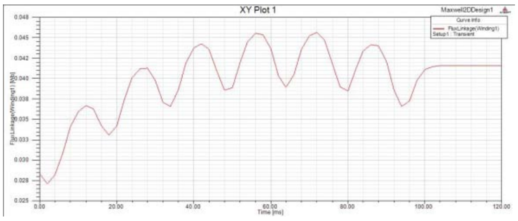

Fig. 9 Flux linkage plot for concept I, case II

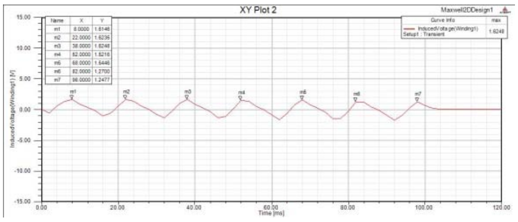

Fig. 10 Voltage plot for concept I, case II

6.2 Concept II

6.2.1 Case I coil connected in series with NdFeB magnet as core and stacked piston

From the Figures 12 and 13 the maximum flux linkage around 0.190 Wb and maximum voltage is 12.5 V. As the piston magnets are stacked one over the other and core is of NdFeB magnet there is marginal increase in the emf generated compared to the case I of concept I.

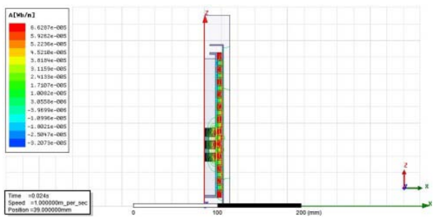

Fig. 11 Flux line plot for concept II, case I

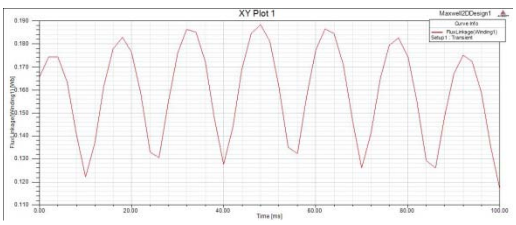

Fig. 12 Flux linkage plot for concept II, case I

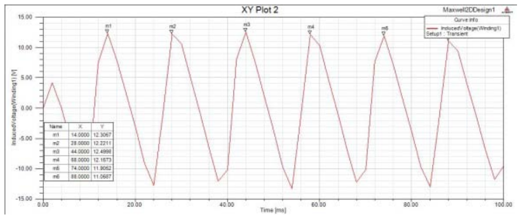

Fig. 13 Voltage plot for concept II, case I

6.2.2 Case II coil connected in series with steel as core and stacked piston

From the Figures 15 and 16 the maximum flux linkage around 0.08 Wb and maximum voltage is 2.5 V. It is clear that compared to the case II of concept I there is increase in emf generated.

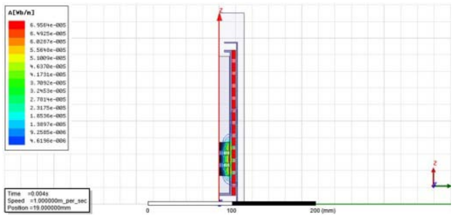

Fig. 14 Flux line plot for concept II, case II

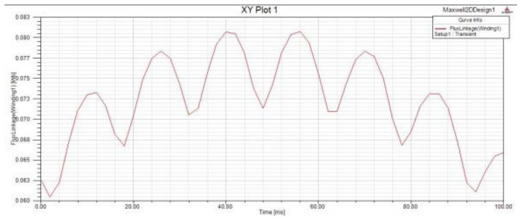

Fig. 15 Flux linkage plot for concept II, case II

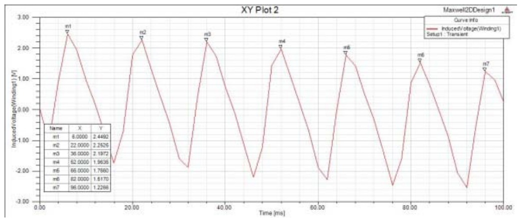

Fig. 16 Voltage plot for concept II, case II

7. RESULTS OF VALIDATION STUDIES

Table 7-1 Voltage recorded in test set up

Velocity in m/sec	Stroke length in mm	Recorded Voltage in volts
1	100	2

7.1 Conclusion

- From the above simulation and validation study it is evident that recovering energy from the kinetic energy of shock absorber is very well possible.
- The simulation results show that by using NdFeB magnets as core material can yield a voltage of 12 V AC
- But the voltage being generated with the technology demonstrator is very limited to 2 V AC. The reason for this could be using steel as core material.
- This voltage is not sufficient to charge the 12V battery which is used in automobiles.

8. REFERENCES

[1] John C. Dixon, *The Shock Absorber Handbook,* 2nd Edition, 2007.
[2] Sawhney A.K., *A Course in Electrical Machine Design,* 6th Edition, 2009.