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DESIGN & DEVELOPMENT OF A REGENERATIVE SHOCK ABSORBER

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ABSTRACT

Vibrations can be accumulated and converted to power in various forms. It is abundantly available in nature. Researchers have been working on tapping its potential majorly as it could solve major energy concerns .They can be captured and harnessed from ambient vibrational sources such as vehicular motion, railway tracks etc. Once harnessed, a variety of applications be it industrial on the large scale or general household on the small scale can be run. Regenerative electromagnetic harvesters implemented on automobiles is one such concept of obtaining electrical output on the large scale, by decreasing the reliance over the existing battery and hence powering up the peripherals by incorporating appropriate changes. Also in turn the overall efficiency of the automobile is increased. Much work has been done on a regenerative electromagnetic shock absorber based on standard data obtained from four wheelers. This paper attempts to obtain an electrical output through a shock absorber using the electromagnetic induction principle for two wheelers. By utilizing the design specifications of a conventional hydraulic shock absorber on the Hero Honda Splendor, a theoretical model is framed which is comparable to the size of the hydraulic shock absorber. Analytical calculations are done to give an idea about the electrical output based on the design. Design of the regenerative shock absorber is done on software. Static magnetic field analysis is carried out at an equilibrium position and the results are plotted. MATLAB was utilized for the solving of analytical calculations. The analytical calculations performed prove the viability of the design.

KEYWORDS—Electromagnetic, Energy Recovery, Regenerative shock absorber, Vibrational Energy.

INTRODUCTION

The percentage of fuel energy in an automobile required to overcome the air drag and resistance due to road friction is only about 10%-16%. Rest of the energy is wasted through various losses such as driveline losses, air drag, rolling resistance, engine losses, braking losses, idling losses. Of all these braking losses contribute about 5.8% of energy lost. Braking loss is considered as the loss of kinetic energy into waste heat due to vibrational motion of the suspension system. In the past hundred years or so, the automobile industry has designed optimal suspension and braking systems such as anti-lock braking systems and active suspensions in order to lessen the amount of waste heat dissipated. Also, regenerative braking has caught the eye of major researchers in the last few decades and its most important application is the braking system on electric trains and vehicles. The main drawback of the regenerative braking principle is that it is not a continuous energy recovery system. Looking at the suspension system to continuously recover energy while in motion is an objective of many researchers provided all factors such as weight, damping output etc. are considered thoroughly. Work on such precision actuators is on the primitive scale as such continuous regenerative systems have not come into practice yet. The conventional shock absorber working in tandem with the suspension spring is merely an energy dissipating device. By changing the internal structure of the shock absorber based on the principle of electromagnetic induction could lead to obtaining an electrical output. In short, a part of the braking loss can be recovered in an electrical form. If harnessed, running of peripheral systems such as air conditioning systems, the radio, headlights, tail lamps, etc could become much easier as this energy recovered would be able to run such applications while also charging the battery simultaneously due to constant motion of the vehicle. The shock absorbers on two wheelers can also be used for energy recovery and the energy recovered can run the aforementioned applications.

LITERATURE REVIEW

Lei Zuo et al. designed an electromagnetic vibrational energy harvester specifically for taking the railway track deflections/ vibrations as their input. It is designed with a patented multiple motion rectifier which basically converts the bidirectional motion to a unidirectional output motion. The preliminary design is made to make sure it runs the high power track side applications such as warning signals, switches and monitoring systems which require at least 10 W of power to run. Moreover power generated is DC as implementation of a flywheel is used[1].Lei Zuo et al. also designed and fabricated a 1: 2 model of a linear generator based electromagnetic shock absorber was done. Finite element method was utilized to analyze the magnetic field and guide the optimization of the design. Experimental tests conducted on the harvester show that the available energy that can be harnessed is between 16 – 64 W at a suspension velocity of 0.25 – 0.5 m/s.[2]Longzinzhen et al. discussed and analyzed the structure and principle of a regenerative electromagnetic shock absorber were analyzed in detail. The design consists of two coil winding arrays as well as two magnet arrays to generate a larger electrical output. Electric power can be re-obtained from the battery and it is produced due to the relative motion of the coil assembly and the permanent magnet. Magnetic flux density was obtained by utilizing the ANSYS software and accordingly performance parameters were obtained.[3]R.A.Oprea et al. provided the theoretical framework for the design of a linear electromagnetic shock absorber that converts the vibrational energy dissipated into electricity is discussed. Also, damping effects due to the design are also taken into consideration. Finite Element analysis is used to obtain the optimum size and configuration including the material to be used. Electro-mechanic and Thermal characteristics are numerically and experimentally investigated.[4]I. Martins et al. compared the design of the electromagnetic shock absorber with the hydraulic active suspension to highlight its commercial usage in the near future. Since active suspensions are too expensive, developments in the power electronics department and the permanent magnet material properties could be tapped so as to achieve better results at an affordable price. The analysis done and the experimental results show that the force values produced by the actuator are suitable and the actuator is oil free. Utilization of such an electrical system allows easier operation and guarantees regeneration of energy in the near future.[5] Lei Zuo et al. also employed the mixed motion rectifier patented technology to the conventional shock absorber by changing the internal structure of the shock absorber with a rack and pinion configuration. Experimental setup done proved to obtain 15 W of power while driving at a speed of 15mph on a B class road.[6].

CONCEPT, DESIGN & ANALYSIS

In this section, at first the concept or working principle of the shock absorber is put forward followed by its design in CAD software. Lastly static magnetic analysis and its results are highlighted and compared with the analytical parameters.

A. Working Principle of the Regenerative shock absorber

The regenerative shock absorber converts suspension vibration between the wheel and the sprung mass into electrical power. The design consists of mainly a coil windings array and a permanent magnet array. The permanent magnet array is concentrically placed on a metallic rod which is of high magnetic reluctance. Along with the permanent magnets the, magnetic permeable spacers are stacked concentrically on the rod and they are placed in between permanent magnets. The permanent magnets are axis-symmetrically magnetized and their orientation takes the form of N-S-S-N. This orientation allows the like poles to repel each other and the magnetic flux to move radially from the north to south of the permanent magnet. The coil windings array is basically a plastic tube on which the coils are wound. Plastic tube is considered due to its high electrical resistivity and less weight. An outer cylinder of magnetic permeable material is used to encase the permanent magnets array and also to reduce the reluctance of magnetic loops and thereby increase magnetic flux through the coils.
The electromagnetic induction principle states that there will be a development of voltage across the ends of a conductor in a magnetic field provided there exists relative motion between the conductor and the magnetic field. In this case, the relative motion is in between the coil windings array and the permanent magnet array. The voltage developed at the ends of a single conductor coil depends on the relative velocity V_Z, between the coil and the magnet array, the remanent magnetic field $B$and the length of the conductor coil, l.. Equation (1) gives us this particular relation.

$$V = BV_Z l \quad (1)$$

Equation (2) gives us the current produced due to the above emf set up in the coil depends on the electrical conductivity of the coil σ, the radial magnetic field of the permanent magnet B_r, the relative velocity V_z and the area of cross-section of the wire A_w.

$$I = \sigma B_r V_z A_w \quad (2)$$

The magnetic field induced depends on the turn density, current and the relative permeability of the conductor material. The length of the coil is given by equation (4).

$$l = \pi D_c N \quad (3)$$

Where $N$the number of is turns of the coil and D_c is the average coil diameter.

B. Design Specifications

Measurements from a conventional hydraulic shock absorber are taken. The outer cylinder OD is found out to be 40 mm and the ID is found to be 35 mm. The axial rod diameter is found out to be 10mm. The axial rod length is 19cm and the extended length and collapsed length of the shock absorber are both 36cm and 30cm. By keeping the axial length of axial rod same and changing the OD to 48 mm and ID of 38 mm so as to make sure that all the necessary components of the assembly fit within the outer cylinder of the design proposed and by employing the industrial standard N35 grade NdFeB permanent magnet of size 20mmx10 mmx10mm, static magnetic analysis was done. The OD and ID of the permanent magnets and magnetic permeable spacers is the same. Mild steel spacers are used due to their high magnetic permeability.The height of the spacers is taken to be 8mm. A copper coil of 30 AWG (American wire gauge) is considered with 250 - 300 turns for being the conductor. The length of the coil is taken as half of the length of the permanent magnet and magnetic spacer combined those results to 9 mm. The coils are made to align with the permanent magnet array. The distance between respective coils is kept as 1mm. The coils are positioned such that they are 90° out of phase with each other. The coils adjacent to the permanent magnets at an equilibrium position will always give an output voltage of 0. Whereas the coils adjacent to the magnetic spacers will give positive and negative peak to peak values of the voltage generated.Fig 1. Represents the model of the assembly incorporating all the above components based on the dimensions selected. The model was designed with the help of CATIA V5 software for better visual understanding.

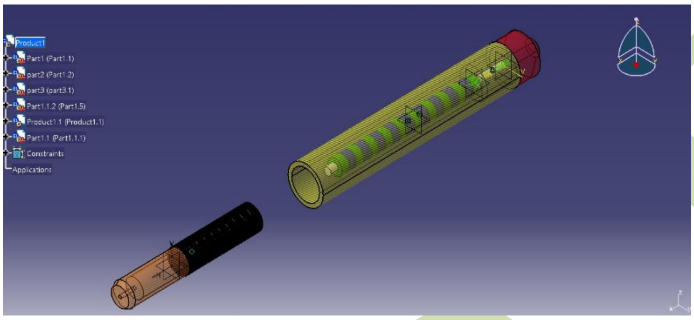

Fig 1. Proposed Design

C.Static Magnetic Analysis

Magnetic field analysis was carried out to confirm with the analytical calculations and to optimize the solution. FEMM 4.2 software was used to showcase the radial magnetic field acting on the coils .Value of radial magnetic field acing on the copper coil was found out to be 0.157T analytically. The initial simulation case with no outer cylinder and axial rod material as stainless steel gave us a value of 0.157 T. By changing the axial rod material to Aluminium we obtain a value of 0.190 T. This is because Aluminium has high magnetic reluctance and hence the magnetic field is pushed towards the coils. By applying an outer casing of mild steel due to its high magnetic permeability gives us a magnetic field of 0.240 T.This says that there is more power that can be extracted from this device due to optimizing the design. Fig 2 –Fig 4 show the magnetic flux distribution within the regenerative shock absorber. The outer tube of mild steel helps in keeping the magnetic flux well within the casing and pushes all the flux through the coils.

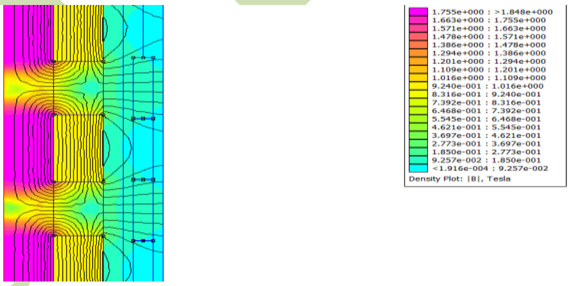

Fig 2. Magnetic field distribution with Stainless steel axial rod

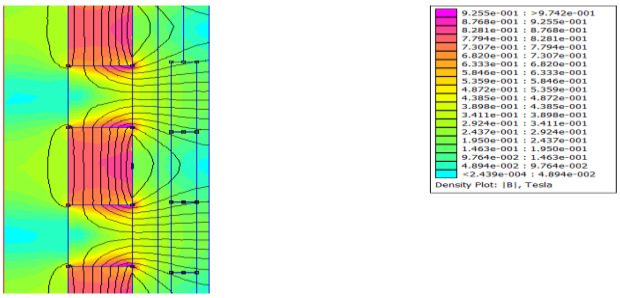

Fig 3. Magnetic field distribution with Aluminium axial rod.

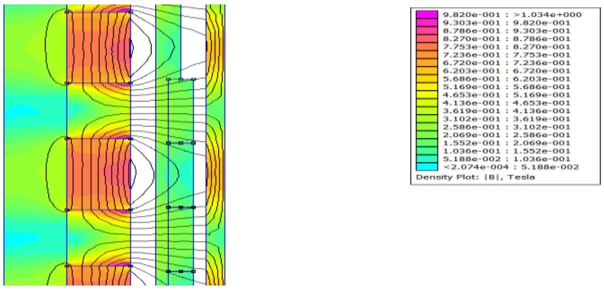

Fig 4. Magnetic field distribution with Aluminium axial rod and Mild steel outer casing.

MATLAB ANALYSIS

The suspension speed experienced by the shock absorber is within the range of 0.2 – 0.5 m/s [2]. Analytical calculations were carried out by keeping in mind the above stated information. The voltage generated within a single coil at 0.2 m/s velocity for a magnetic field of 0.24 T for a length of the conductor being 22.608 m was found out to be 1.085 V. Similarly for 0.5 m/s the voltage generated gives an analytical value of 2.713 V.

MATLAB software was utilized to calculate the regenerated voltage for a single coil within the proposed model. The input displacement was considered to follow a sinusoidal pattern dependant on frequency given by Equation (4)

$$x = X_{max} . \sin(w.t) \qquad (4)$$

Where Xmax = 10 mm, i.e. the maximum length traversed by every single point on the coil while in motion.

By differentiating the above, we obtain the velocity experienced by the coil and is given by equation (5)

$$v = X_{max} . w. \cos(w.t) (5)$$

The magnetic field itself given by equation (6) will follow a sinusoidal pattern while the coil moves in and out of a magnetic field emanated from the permanent magnets of different polarity and the value of the varying magnetic field experienced by the coil is dependent on the motion of the coil within the magnetic field within a distance of 0 to 10 mm. The magnetic field is given by

$$B = B_{max} \cos\left(\frac{\pi x}{L}\right) (6)$$

Where L = thickness of spacer plus magnet i.e. 20 mm.
Bmax = 0.24 T, maximum magnetic field obtained by
optimizing the construct of the proposed model.

Then equation (7)gives the regenerated voltage

$$V = B.v.l \qquad (7)$$

The frequencies were varied between 5 Hz and 12 Hz and rms values for the regenerated voltages were calculated for the same. MATLAB analysis shows the RMS voltage results for 5 Hz as 0.9422 V and for 12 Hz as 2.23 V. It was seen that the analytical results and the MATLAB simulation results match.
Fig 5 and Fig 6. Represents the waveforms for excitation frequencies of 5 Hz and 12 Hz respectively.

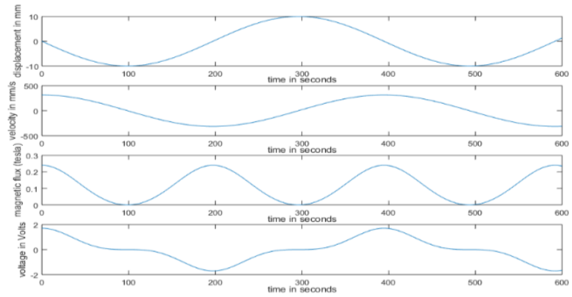

Fig 5. Waveforms of displacement,velocity, magnetic field & regenerated voltage for excitation frequency of 5 Hz

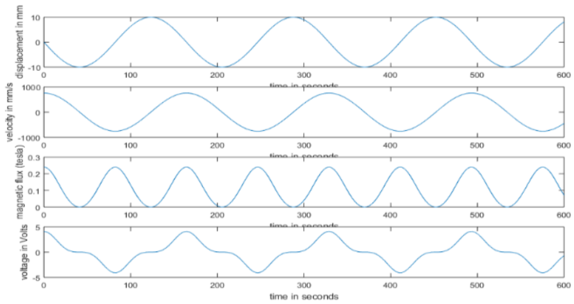

Fig 6. Waveforms of displacement,velocity, magnetic field & regenerated voltage for excitation frequency of 12 Hz

CONCLUSIONS

This paper talks about the choice of materials required for the construction of the regenerative shock absorber. Moreover, the magnetic field analysis done and the analytical calculations prove that the scheme for this model is viable.
The analytical calculations give values for the regenerated voltages for 0.2 m/s and 0.5 m/s as 1.085 V and 2.713 V respectively. MATLAB analysis done by varying frequencies as 5 Hz (RMS velocity is 0.223 m/s) and 12 Hz (RMS velocity is 0.538 m/s) and keeping the maximum displacement constant gives the RMS regenerated voltages as 0.9422 V and 2.23 V. From the waveforms we also understand that as frequency is increased, output voltage increases.
The MATLAB analytical calculations match the rough general principle calculations and prove the viability of the design. The proposed model can be validated experimentally by fabricating a prototype and testing on an electrodynamic vibration shaker.

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