Design & Experimentation Vibration Energy Harvesting using Shock Absorbers

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Abstract— Transportation accounts for 70% of oil consumption, and yet only 10-20% of the fuel energy is used for vehicle mobility. One of the important losses is the energy dissipation in suspension vibration. The objectives of this thesis are to investigate energy recovery from vehicle suspensions by answering two questions: (1) how much energy is available while meeting the primary functions of shock absorbers? (2) How can the wasted energy be converted efficiently to electricity? To answer the first question, a vehicle-ground model, including the stochastic property of road roughness, vehicle parameters, travelling speed, is created with analysis of ride comfort, road safety, and vibration energy induced by road roughness. We found that the dissipative power from all four shock absorbers for a typical mid-size passenger car on ISO class B (good), C (average), and D (poor) roads are approximately 100, 400, 1600 Watts respectively. The sensitivity of the power generation, ride comfort and ride safety to various operational vehicle parameters are further analysed. Results indicate the power generation is mainly dependent on the tire stiffness in which the higher tire stiffness is, the more power generation. However, higher tire stiffness will cause a less comfort and more dangerous ride. Therefore, larger sprung mass will be preferred for achieving a more comfort and safer ride to compromise the negative effects of high tire stiffness. More importantly, the suspension damping also plays as an important role on ride comfort and safety aspects. A more comfortable ride can be accomplished with softer damper. As a trade-off, the probability of losing ground contact increases which will cause handling issues and safety hazards.

Key words: Suspension; Regenerative Damper; Energy Harvesting; Electromagnetic Shock Absorber; Fe magneto Static Analysis

I. INTRODUCTION

In the last years, automotive research aims to maximize the passengers comfort and the efficiency of all vehicle components. Especially in hybrid vehicles, the energy losses have to be minimized, by recovering more energy as possible from all installed devices. The kinetic energy is commonly dissipated into heat in the case of brakes or suspensions. The amount of recoverable braking energy is much higher than is possible to obtain by a suspensions system. However, there are many studies regarding the possibility of energy harvesting by the vehicles suspensions using electromagnetic dampers which have to be compact and efficient. For this reason, almost all solutions of electromagnetic dampers are based on the use of rare-earth permanent magnets. The electromagnetic dampers are not only used in automotive field, but even in civil structures in order to damp the vibrations and thereby reduce or eliminate the noise.

In this paper, review of various vibration energy shock absorbers taken place. Energy harvesting device convert ambient energy into electrical energy. Some system converts motion ocean waves into electrical energy. Energy Harvesting is the process by which energy is derived from external source that can be captured, stored in device. This energy can be stored in capacitor or battery. Energy harvesters provide a very small amount of power for low-energy electronics. While the input fuel to some large-scale generation costs resources (oil, coal, etc.), the energy source for energy harvesters is present as ambient background and is free. For example, temperature gradients exist from the operation of a combustion engine and in urban areas, there is a large amount of electromagnetic energy in the environment because of radio and television broadcasting. In the most general terms, energy harvesting (also referred to as energy scavenging or power harvesting in the literature) describes a process whereby energy in a given environment is transferred into a more useful form of electrical energy. Energy is the amount of power consumed, expressed in watt-hours or kilowatt-hours, while power is often expressed in watts or kilowatts. Energy is equal to the power multiplied by the time of consumption. Thus, in specific terms energy harvesting is somewhat of a misnomer, as technically the area should be referred to as power harvesting (although following common convention the term energy harvesting will be used here). The sources of energy that can be harvested are practically limitless, and in the most general terms can include sources such as solar energy, thermal energy, wind energy, tidal and wave energy, and mechanical and vibration energy. Further, the scales on which energy harvesting can be pursued can vary drastically, generating anywhere from utility-level power levels in applications such as hydroelectric dams, wind (turbine) farms, and solar (or photovoltaic) applications to energy harvesting at much smaller scales, where micro- (or even nano-) watt levels of electrical energy that are generated are useful for a small-scale device or system.

II. LITERATURE REVIEW

1) Suda et al. [1996]. Investigated a self-powered active suspension control system, in which one motor is used to generate electricity and another motor is used to control the vibration. Nakano also investigated the self-power vibration control using a single motor, in which a variable resistor, a charging capacitor and relay switches were used to control the motor force to follow the desired skyhook damping force. Paper proposes new control concept of suspension, i.e. a hybrid control system with active control and energy regeneration. In ordinary passive suspension system, damper converts vibration energy into heat energy by its viscosity, so that the vibration energy is dissipated. This dissipated energy is
not used practically at all. On the other hand, active suspension system has great performance of vibration isolation but it consumes extra energy. This paper presents a method to solve these problems in active and passive control systems as follows: In passive suspension an energy regenerative damper system which converts vibration energy into useful energy is proposed. The hybrid system combines this energy regenerative system and active control in order to achieve good performance of vibration reduction with few energy consumption. By numerical simulations and basic experiments it was found that the proposed hybrid control system had satisfactory performance in both vibration reduction and energy consumption.

2) Amati et al [2011]. Electromechanical dampers seem to be a valid alternative to conventional shock absorbers for automotive suspensions. They are based on linear or relative electric motors. If they are of the DC-brushless type, the shock absorber can be devised by shunting its electric terminals with a resistive load. The damping force can be modified by adding on the added resistance. To supply the required damping force without exceeding in size and weight, a mechanical or hydraulic system that amplifies the speed is required. This paper illustrates the modeling and design of such electromechanical shock absorbers. This paper is devoted to describe an integrated design procedure of the electrical and mechanical parameters with the objective of optimizing the device performance. The application to a C class front suspension car has shown promising results in terms of size, weight and performance. Do not mainly consider the size, regenerated power and road induced vibration energy.

3) Sethu Prakash S et al [2015]. In the past decade, regenerative braking systems have become increasingly popular, recovering energy that would otherwise be lost through braking. However, another energy recovery mechanism that is still in the research stages is regenerative suspension systems. This technology has the ability to continuously recover a vehicle's vibration energy dissipation that occurs due to road irregularities, vehicle acceleration, and braking, and use the energy to reduce fuel consumption. A regenerative shock absorber is a type of shock absorber that converts intermittent linear motion and vibration into useful energy, such as electricity. Conventional shock absorbers simply dissipate this energy as heat. Regenerative shock absorbers utilize piston cylinder arrangement or generation of electricity. Piston undergoes compression and expansion with movement of vehicle. The system is designed in SOLIDWORKS. When used in an electric vehicle or hybrid electric vehicle the electricity generated by the shock absorber can be diverted to its power train to increase battery life. In nonelectric 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. This could be used on electric or hybrid vehicles (or normal vehicles) to capture energy which would otherwise be absorbed and wasted, and then convert it into electricity. The regenerative shock absorbers can harvest the power in a continuous way. We analytically determine the pressure and velocity at 0.5Hz and 1Hz. A graph is plotted between pressure and velocity. Analysis is performed in CFD and values are determined.

4) Bogdan Sapiński et al [2016]. The study investigates an energy harvesting system utilising rotary motion. The system has three components: a rotary MR damper to vary the damping characteristics, a rotary power generator (energy extractor) producing electrical power, and a conditioning electronics unit to interface directly with the damper and the generator. The objective of the study is to examine the system performance through experiments. The paper outlines the structure of the damper and the generator, provides selected results of examination of the system components and the whole system under idle run and under load for the assumed speed range. The results demonstrate that the system is adaptable to external excitations, does not require an extra power supply and provides a smart solution with potential applications to rotary motion control.

5) Meghraj P.Arekarl, Swapnil Shahade et al [2015] an electromagnetic linear generator and regenerative electromagnetic shock absorber is disclosed which converts variable frequency, repetitive intermittent linear displacement motion to useful electrical power. The innovative device provides for superposition of radial components of the magnetic flux density within a coil winding array. Due to the vector superposition of the magnetic field and magnetic flux from a plurality of magnets, a nearly four-fold increase in magnetic flux density is achieved over conventional electromagnetic generator designs with a potential sixteen-fold increase in power generating capacity. As a regenerative shock absorber, the disclose device is capable of converting parasitic displacement motion and vibration encountered under normal urban driving condition to a useful electrical energy for powering vehicles and accessories or charging batteries in electric and fossil fuel powered vehicles. The disclosed device is capable of high power generation capacity and energy conversion efficiency with minimal weight penalty for improved fuel efficiency.

III. METHODOLOGY

1) Experimentation is performed on shock absorber damper using load cells.
2) Using MATLAB simulink software the force vs velocity graph is plotted
3) With the help of Catia, 3D CAD model is prepared of energy harvester.
4) Twin tube shock absorber is used.
5) Loads are applied using load cell unit and DSO for voltage plot.
6) Linear generator is used which comprises of two main parts; coil winding (1) and stack of rare earth magnet (2).
7) The conductor consists of cylinder and coil, while translator consists of rod/piston mechanism composed of permanent magnets and poles.
8) To design and manufacture the energy harvesting shock absorber similar to Kirk Rhodes Model
9) The output of Experimentation is compared with MATLAB Coding.
10) The two results (test & Coding) correlate well with each other.
11) Based on validation of Matlab coding and experimentation data voltage output is calibrated
12) Finally Force Vs Velocity and Force Vs displacement data has been plotted using simulink Matlab software.
13) There are various methods of energy harvesting using different energy sources.

IV. EXPERIMENTAL PROCEDURE
1) Test Model is fixed on the load cell unit
2) D.C output wires are connected to strings of coil winding.
3) DSO is placed separately on the load cell unit.
4) Using load cell vibrator and DSO Voltage output graph is plotted.
5) Using Matlab coding output graph of displacement Vs power graph is plotted.
6) Comparing with kirk's model force Vs velocity and Force Vs displacement graph is validated.

V. MATLAB CODING
MATLAB is the software where multiple matrices can be solved in one operation further is the program coding of
pressure of fluid is converted into power and displacement of string Vs power generated graph is plotted.

A. Coding Inputs
- Stiffness of spring=2 N/m,
- Kinematic viscosity (u)=18 m²/s,
- Discharge Coefficient (Cd)=0.7,
- fluctuation coefficient (Cf)=0.3,
- Density of oil = 860 Kg/m³,
- Velocity of fluid=0.1:0.1:1 m/s

Table 2 Output of MATLAB Coding

<table>
<thead>
<tr>
<th>Input Y</th>
<th>0.690</th>
<th>4.560</th>
<th>11.010</th>
<th>20.040</th>
<th>31.350</th>
<th>45.840</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Power</td>
<td>1.0e+01*</td>
<td>0.0441</td>
<td>0.1019</td>
<td>0.1723</td>
<td>0.2383</td>
<td>0.3570</td>
</tr>
</tbody>
</table>

B. Simulink Valve Model
Simulink valve model is the type of electric circuit diagram used to solve number of equations simultaneously. These circuit diagram uses the blocks of hydraulic, pneumatic loads.

Fig. 6: Output of MATLAB Coding Power Vs Displacement

Fig. 7: Simulink Model for Force Vs Velocity Graph

Fig. 8: Force Vs Velocity Graph from Simulink Model

C. Force Vs Displacement Simulink Model

Fig. 9: Force Vs Velocity Graph of Simulink Model

VI. CORRELATION BETWEEN TEST & MATLAB CODING RESULTS
For correlation, plot of frequency Vs voltage output graph is compared with displacement Vs power output graph in MATLAB.
- Test Results
  1) Frequency: 4 Hz, Corresponding Amplitude: 630mm
  2) Voltage output for 4 Hz frequency: 1.50 volts
- Simulation Results
  1) Displacement of string: 0.690m
  2) Power output for displacement of string: 1.0e+01*
From the above it has been concluded that test results and Matlab coding result correlates with each other. Therefore Matlab coding can be used to observe how real based models can generate voltage output in terms of power.

Frequency Vs Voltage output plots are obtained from the test done on the harvester using the load cell unit/load cell shaker and the output can be obtained using DSO unit.

VII. RESULTS

Frequency Vs Voltage output plot is obtained of the output table of test data and plotted in the form of graph. The line in blue represent continuous voltage output table and same in represented in MATLAB coding graph.

<table>
<thead>
<tr>
<th>Input</th>
<th>Result Table</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn No</td>
<td>Frequency Hz</td>
<td>Amplitude (mm)</td>
</tr>
<tr>
<td>1</td>
<td>2 Hz</td>
<td>550 mm</td>
</tr>
<tr>
<td>2</td>
<td>3 Hz</td>
<td>572 mm</td>
</tr>
<tr>
<td>3</td>
<td>4 Hz</td>
<td>630 mm</td>
</tr>
<tr>
<td>4</td>
<td>5 Hz</td>
<td>230 mm</td>
</tr>
</tbody>
</table>

Table 3: Frequency, Corresponding Amplitude & Voltage Output

The MATLAB coding of displacement of string and the power output generated is plotted in the result of MATLAB window.

Table 4: Input is Displacement of the String & Output is Power Generated

The figure shows there is power generation continuously through the displacement of string but somewhat in the mid there is slag these is only the difference between Matlab coding and test result output.

VIII. CONCLUSIONS

Based on test and simulation results following points have been concluded.

- We can harvest energy using shock absorber upto 1.5 volts of energy.
- Designed and manufactured the shock absorber like Shawn Rhoades model.
- Tested the energy harvesting capacity of shock absorber.
- Prepared the valve models for Force Vs velocity graph and Force vs displacement graph.
- Validated the graphical output of valve model with Shawn Rhoades model.
- Experimental Results are compared with MATLAB Simulation coding for Validation.
REFERENCES

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[10] Development and Experimental verification of a parametric model of an automotive damper a thesis by Kirk Shawn Rhoades