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A Review on Regenerative Shock Absorber

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Abstract - Automobile suspension system dissipates the energy in the form of heat which is treated as the complete waste. Regenerative suspension system have attracted much attention due to reduction of energy dissipation. Regenerative Shock Absorbers have the ability to harvest some amount of energy from the vehicle suspension system, which is otherwise be wasted as heat. This paper introduces existing research on regenerative suspension system and reviews the potential of vibration energy, relationship between the power and road surface with respect to various parameters, classification of Regenerative suspension system and regenerative techniques.

Key Words: Energy Harvesting, Suspension, Regenerative Shock Absorbers, Energy Conversion Mechanisms

1. INTRODUCTION

Energy harvesting is the process of collection of small amounts of energy from any of the sources and converting it into the electrical energy. While travelling on the road surfaces, vehicles subjected to different excitations due to road irregularities. Only 14 – 18% energy of the fuel is utilized to actually move the vehicle while remaining is wasted either in the form of cooling, exhaust and suspension system. Energy is a most essential key in the world. So reducing the energy loss is a need for improving the fuel efficiency. In the suspension system, shock absorber is the main mechanical device which absorbs the road vibrations and convert it into heat energy which is dissipated in the environment treated as complete wastage. So, the regenerative shock absorbers have the tendency to harvest the wasted energy. Regenerative Shock Absorbers was proposed two decades ago, for the purpose of harvesting the energy, but over the past 10 years it gains much attention because of ability to convert irregular vibration into the regular motion. A regenerative shock absorber converts linear and vibration motion into electricity. Various classification of suspension system is also described, as it is also important that how the energy is transformed from source to the receiver end.

2. LITERATURE REVIEW

Energy harvesting potential and its effect have been estimated by several scholars. Lei Zuo and Pei Zhang [1] demonstrated, 100-400W energy is available at 60mph which correspondence to 3% fuel efficiency. By adopting the regenerative shock absorbers there is a possibility of co_2 emission, it also improves the fuel efficiency. So, there is a possibility of reducing the greenhouse effect which helps to save the environment from the poisonous gases up to some extent. The co_2 emission is reduced up to 3gm/km for the hybrid passenger automobile and the dissipated energy have a tendency to improve the fuel economy by 0.7 liter per 100km [2].

The regenerative shock absorbers classified as linear electromagnetic and rotary electromagnetic harvesters, as it is strongly impact on output how the vertical vibration is translated into the electricity [3, 4]. Again rotary electromagnetic harvesters are possesses two mechanism either hydraulic or mechanical transmission. The mechanical transmission systems are of various types which includes the rack and pinion mechanism, ball and screw mechanism, etc. Out of mechanical and hydraulic transmission system, mechanical one has higher efficiency, simple in construction [5]. Zhu S et al. [4] carried out analytically and experimentally the conversion efficiency, power output and damping behavior of linear electromagnetic harvesters with the help of circuits. For the 2 Hz input frequency the conversion efficiency obtained is varied from 14 to 25 % for an amplitude of 3 and 6mm while for 6 Hz input frequency the conversion efficiency obtained is 33 % for an amplitude of 11 mm. Zhongjie Li et al. [6] described the innovative design of regenerative shock absorber with rack and pinion transmission system having advantage of significantly improving the energy harvesting efficiency and reducing the impact forces caused by oscillation. Md. Emran Hossain et al. [7] created the rack and pinion model for harvesting the energy which is wasted when the vehicles pass over a speed breaker which converts rotational energy into electrical energy and 6.6 W energy is harvested but when compared with the analytical methods finds an error of an 25.91%. Shreyas Honagekar et al. [9] designed the rack and pinion mechanism for the purpose of energy harvesting in the suspension system and results are obtained in quarter deflection, semi deflection and in full deflection and the energy harvested as 1W, 2W and 2.8W Yilun Liu et al. [8] described the energy harvesting shock absorber using a ball-screw mechanism and two one-way clutches are used to replace conventional

oil dampers in vehicle suspensions and achieves high energy-harvesting efficiency. Seema Tiwari et al. [10] examines how the energy dispersal from the vehicle suspension system and from the investigation, it is said that energy dissipated not only depends only upon the vibrations but also the speed and mass of the vehicle and the recovered energy is used for controlling the dynamic suspension then differentiate the regenerative shock absorbers based on utilizing the linear generator and rotary generator using either hydraulic or mechanical transmission. Waleed Salman et al. [21] performed simulation using MATLAB to evaluate the force displacement relationship for the different vibration input and also performed the bench tests and maximum energy produced is 270 W. Li C et al. [24] investigated the conversion efficiency of 39% at the frequency input of 2 Hz when the amplitude is 8 mm.

This review provides the current research of energy harvesting from the vehicle suspension, the potential of vibration energy to determine what amount of energy is available for being harvested. This paper also presents the analytical and statistical survey which includes the conducted simulations, road tests and bench tests.

2.1 Potential of Vibration Energy

Energy could be converted from one form to other [11]. So, for converting mechanical energy into the electrical one electromagnetic and piezoelectric methods are widely used. Electromagnetic harvesters used for large scale whereas piezoelectric harvesters used for small scale [12]. While comparing energy harvesting methods, it is observed that overall efficiency of 20 and 40 % is achieved in case of machine vibration as an energy source compared to other sources like thermal, wind and solar energy sources [13]. So, based on the potential capacity of damper, the energy harvesting technology is a very promising track to do the research.

While travelling on the road surface, vehicle consumes only 14 – 18% energy of the fuel to actually move the vehicle while remaining one is wasted in the form of exhaust, cooling, friction losses such as rolling resistance, air drag, brakes, transmission and engine losses [14]. So, to reduce the emission and for improving the efficiency of fuel reducing the energy losses are necessary. As energy is rare and expensive so the harvested energy have worth more even it is harvested in a small quantity.

To determine the power dissipation by the damper, the potential power is determined as the product of suspension relative velocity and the damping force [15].

$$P_i = F_d \times V_s \quad (1)$$

Where,

P_i = Instant power

F_d = Damping Force

V_s = Suspension Velocity

Carruthers IDB[16] predicted energy dissipation from the damper for the different road profiles and the vehicle velocities and according to his results each damper dissipate 20 W energy under city driving conditions, while dissipate 80 W energy under the higher velocities. Lei Zuo, Pei Shang Zhang [1] done on – field tests (Fig. 1) and stated that RMS for dissipated power per damper was 5W (for class B road), 15W (for class C road), 37W (for class C road). Also, investigate analytical potential power was in between 100 -400 W for passenger cars when car is at the speed of 60mph and increasing the tire stiffness, it generates more power. Khoshnoud et al. [17] determined the recovered power analytically as 1.1KW, 0.88KW and 97KW for three different quarter car models. Lafarge et al. [18] determined the power dissipated in the vehicle suspension system for 2 DOF quarter car model and 4 DOF half car model for the 5 mm amplitude and 10 Hz input of sin wave and according to their results: for the quarter car model the energy harvesting potential obtained is 280 W and for the half car model this value increases to 305 W. The power dissipated during the suspension is strongly depends on road roughness, driving speed and tire stiffness [15].

3. Energy Conversion Mechanisms

Vehicle while moving on the road surfaces experiences uneven disturbances. As previously stated in the literature regenerative suspension based on electromagnetic harvesting is the most promising technology because simple in design, higher conversion efficiency and higher energy recovery. The regenerative shock absorbers classified as rotary electromagnetic and linear electromagnetic harvesters as stated earlier.

Fig -1: Experimental Setup: Road tests of Super Compact Vehicle on Stony Brook campus road [1]

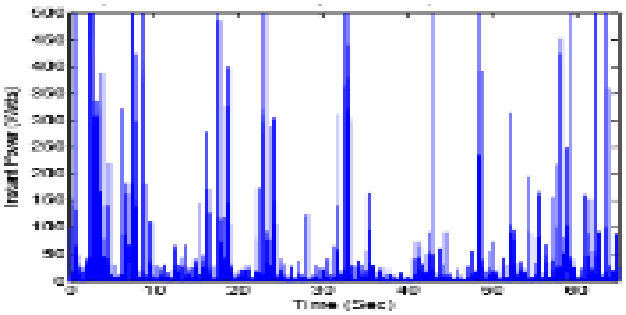

Fig -2: Energy dissipation rate of one shock absorber at vehicle speed 25 mph [1]

3.1 Electromagnetic linear harvesting shock absorbers

It directly transforms the kinetic energy of suspension into the electric one by the electromagnetic induction without any transmission mechanism. It has two major parts which has coil assembly and magnet assembly. The

magnetic arrangement contains ring shapes spacers and permanent magnets [19] (Fig. 3).

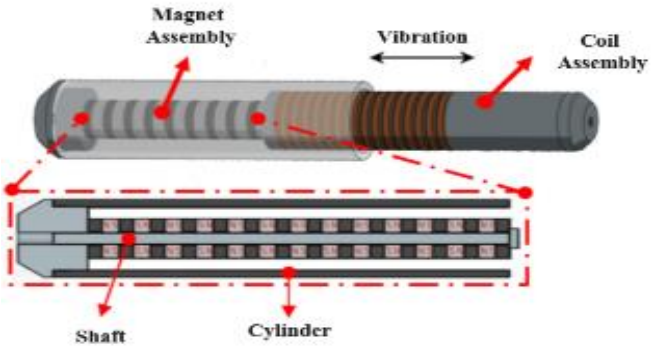

Fig -3: Linear electromagnetic based energy harvesting shock absorber [19]

As the vibration takes place it causes the movement of magnets with respect to coil. This motion causes the variation in the magnetic flux inside the coil and voltage at this point is measured according to Faraday's law which is given by [20],

$$e_v = -\frac{d\emptyset}{dt} \quad (2)$$

Where,
e_v= induced voltage
$\emptyset$ = magnetic flux

Mapelli F et al. [26] performed the simulation on different roads for 3 DOF quarter model which depends on linear permanent magnet alternator. It is found that power of 50W is recovered for good road condition and for poor road condition this value is obtained as 100W when the vehicle speed is in between 20 and 140 km/hr.

3.2 Electromagnetic rotary harvesting shock absorbers

In this case the vibration is transformed into the rotational motion but transmission mechanism is needed which are either mechanical transmission or hydraulic transmission.

Mechanical transmission system is highly preferred due to simple in construction and higher conversion efficiency [5]. Many scholars described the rack and pinion transmission system [6, 7, and 9], ball and screw mechanism system [8] as a mechanical transmission system. Waleed Salman et al. [21] designed the regenerative shock absorber by using other mechanical based system by using helical gears arrangement for less friction and smooth transmission (Fig. 4.) and also described the suspension, transmission and generator module. It consists of shaft having helical grooves with two hand helix, two guide cylinders, two tapered roller bearings, two roller clutches for converting bidirectional motion into unidirectional and two helical gears. Wang X [21] described the rack and pinion system (Fig. 5), as the vehicle moves on uneven road surfaces vibrations are translated with the help of rack and pinion arrangement into the rotational motion by using two perpendicular bevel gears. Li Z et al. [23] designed the rack and pinion arrangement and performed both the on field tests and laboratory testing. For a 30 mm excitation and 0.5 Hz frequency attained the efficiency of 56%. Also, recovered 19.2 W power when the speed of vehicle was about 48km/hr.

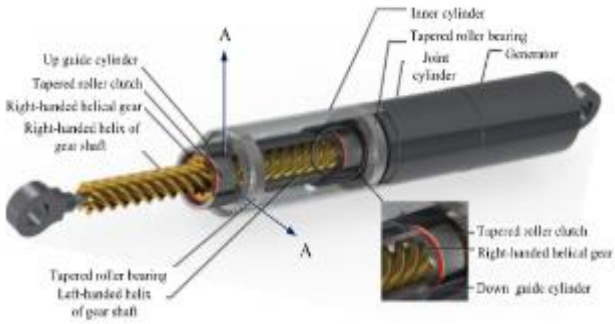

Fig -4: Helical Regenerative shock absorber [21]

Zhongjie Li et al. [6] modelled the overall system of rack and pinion as circuit in MATLAB Simulink and simulation is performed. Also, road tests are performed on Chevrolet SUV and average power of 15.4W when vehicle is at speed of 15mph is obtained.

Hydraulic transmission system are of higher costs than the mechanical one and are highly depends on the hydraulic fluid. Li C et al. [24] created the damper based on hydraulic transmission (Fig. 6) depending on four sets of check valve for the purpose of rectification hydraulic motor

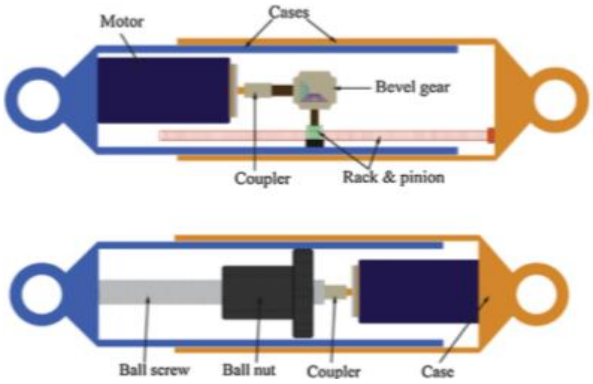

Fig -5: Rack and pinion mechanism [22]

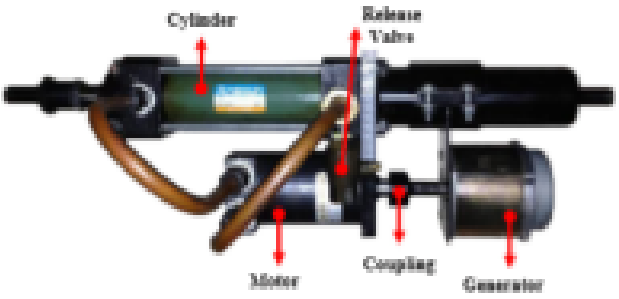

Fig -6: Prototype of hydraulic based shock absorber. [24]

According to Li C et al. [24] the maximum recovered power obtained is 248.8 W with the 39% of maximum efficiency. Obeid HH et al. [25] described hydraulic based transmission and recovered the energy which is wasted by the vehicle brakes and obtained the recovered power as 2.2 W when the vehicle speed was 40km/ hr.

4. RESULTS AND DISCUSSIONS

Analytical potential power was in between 100 -400 W for passenger cars when car is at the speed of 60mph and increasing the tire stiffness, it generates more power and as the stiffness of tire increases, it generates the more power but ride comfort has been compromised which indicated only tire stiffness has influence on power [1]. Figure 7 shows the suspension power for the different speeds also comparison is made to distinguish the comparison between the analytical and measured values.

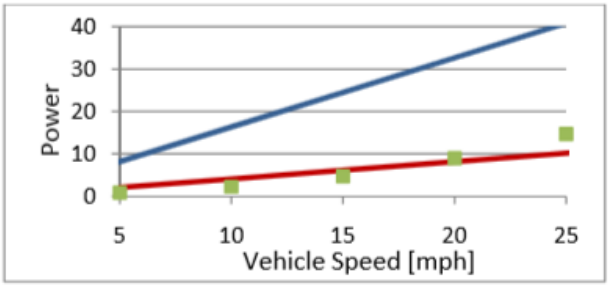

Fig -7: Comparison of Analytical (Red line) and Measured (Blue line) Suspension power [1]

Due to higher conversion efficiency and simplicity in construction mechanical system of transmission is highly preferred [5]. As the vehicle velocity increases, more potential is available for the purpose of harvesting the energy. As the electrical load is to be increase then mechanical efficiency is to be reduced for the 5 mm input excitation as shown in the figure 8.

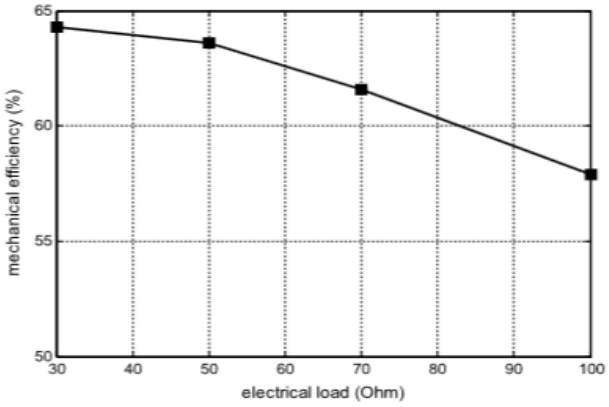

Fig -8: Mechanical efficiencies for 5 mm excitation and different loads [6]

As energy is rare and limited, so further research in the regenerative shock absorbers is very promising track which recovers some amount of energy which otherwise be wasted as heat energy. This wasted energy is much enough to utilize for other purposes.

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