Abstract

Conventional fluid dampers are providing a reliable and low cost solution in vehicle vibration attenuation over the years. However, these convert vibration energy into heat, which is dissipated to the surrounding. A device capable of converting significant part of this energy into useful electric power, will improve overall fuel efficiency of the vehicle. In response to growing concern for increasing fossil fuel consumption in automobiles, energy harvesting shock absorbers have been extensively explored since past two decades. Electromagnetic dampers with linear or rotary configurations have been used to assist energy dissipation and generation in vehicle shock absorber. The prospective innovative suspension solution requires not only conformance to handling and comfort specifications, but also to convert substantial part of vibration energy into useful electric power. Electromagnetic dampers are emerging as a new technology with developments in the field of high energy magnets and power electronics.

Recently, use of ball-screw arrangement and mechanical gears for velocity amplification has substantially improved power output from electromagnetic devices. Although demonstrating improved harvesting efficiency, commercial version of an electromagnetic shock absorber has not evolved. Regenerative electromagnetic shock absorbers are expensive and have higher weight. Moreover, these have non-uniform energy dissipation and limited fail-safe characteristics. Damping coefficient of these devices is also significantly affected by electrical load. For developing a feasible regenerative suspension solution, the above challenges need to be addressed.

Focus of the presented research work is to develop an energy efficient suspension (generation) unit, which can replace conventional fluid shock absorbers. Hybrid Electro-Magnetic Hydraulic Shock Absorber (EMHSA) proposed in the presented research work, offers potential to convert significant part of the vibration energy in to useful electricity, which will improve overall fuel efficiency of the vehicle. The proposed solution exhibits improved energy dissipation and gives consistent damping performance for change in the electrical load. Besides having simple and low cost construction, it also addresses fail-safe issue of electromagnetic harvesters discussed in the literature. Further, it has been verified that hydraulic and electromagnetic damping can be integrated to develop new types of
suspension (generation) unit that has reliability of passive system along with power generating capability. Innovative use of mechanical linkages has been used for increasing power output from the device. In comparison to the existing methods for velocity amplification, the presented solution is efficient, inexpensive and easy to use.

In order to achieve the desired objectives, numerical simulation and experimentation on prototype linear generator and shock absorbers have been performed. Finite element analysis and simulations on the mathematical model have been used to optimize the linear generator configuration. Electro-mechanical parameters of the harvester have been characterized in terms of its dimensions, coil specifications and electrical load. Non-linearity of the electromagnetic damping coefficient has been investigated with discussion on factors affecting the same. Prototype shock absorbers were evaluated for comfort and handling, with numerical simulations on the quarter car model. Theoretical findings are then validated with time/frequency domain analysis of the generator and regenerative shock absorbers.

In the presented thesis, first theoretical framework for design of a linear generator to be used in vehicle suspension, has been explained. Numerical analysis of the generator is supported with experimentations on a prototype consisting of rare earth magnets. The output electrical power is used to charge a 6 V battery. The prototype is connected to a supporting hardware which ensures continuous braking effect on the coil windings.

Two Electro-Magnetic Hydraulic Shock Absorbers are presented in this thesis. First (EMHSA-1), operates with linear generator and displacement sensitive fluid damping. It is demonstrated that the prototype EMHSA-1 gives 124 W of peak power (at excitation velocity of 0.42 m/s). However, with weight of 21 kg it has limited practical viability. The other design (EMHSA-2) amplifies the shock absorber relative displacement to improve the harvesting efficiency.

EMHSA-2 uses mechanical links for increasing relative velocity of the generator coil winding. This device uses fluid and electromagnetic damping for dissipating the vibration energy. Incorporation of the proposed devices can harvest 100-227 W of peak power from each wheel for low to medium suspension vertical velocities. Numerical simulation has been performed to find configuration of the fluid damper and electromagnetic harvester for desired damping coefficient. In comparison to devices
discussed in the published literature, proposed solution has simple construction and requires no external power supply. Moreover, with fewer numbers of components, inertia of the system is not significantly affected.

Along with the output electrical power, performance characteristics for vibration isolation and vehicle handling have also been evaluated for the presented solution. These include sprung mass acceleration, motion transmissibility and \textit{rms} tire deflection. Numerical simulation has been performed to build theoretical model of the shock absorber, which has been validated by experimental approach. A computerized test set up is established to evaluate three degree of freedom quarter car model, within test frequency range of 0 - 6 Hz.

In the presented research work, an attempt has been made to develop an efficient and reliable regenerative shock absorber. It is anticipated, that the presented experimental and simulation results will be of great value to the designers and manufacturers in developing more sophisticated electromagnetic suspension system.

Keywords: Shock absorber, Electromagnetic damping, Damping coefficient, Motion transmissibility, Acceleration transmissibility, Wheel motion, Fluid damping, Automobile suspension, Regeneration.