Power Generation through Rack & Pinion in Suspension System for an Automobile

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ABSTRACT

Energy absorbed by shock absorber is dissipated in terms of heat. Thus in this work attempts have been made to convert dissipated energy in to electrical energy. In this project, design of regenerative suspension system is proposed, for improving the energy harvesting efficiency. Mechanical motion rectifier is used to convert oscillatory vibration into unidirectional rotation of generator. Modal and Vibration analysis is carried out of rack and pinion system to identify displacement and stresses by using software, at various loads. Mode shapes are determined for each natural frequency. Mechanical rack and pinion system is used to generate power through regenerative shock absorber. This system can be used effectively in vehicles for power generation.

Keyword: - *Shock absorber, Regenerative suspension, Mechanical motion rectifier, Rack and pinion etc.*

1. INTRODUCTION

The suspension systems are used in vehicle to support weight of vehicle body and to isolate the vehicle chassis from road disturbances. The dampers are designed to dissipate vibration energy into heat so as to reduce the vibration transmitted from road excitation. It is feasible to harvest this vibration energy from the vehicle suspension system to improve the efficiency of the vehicle. The suspension system used for the regeneration of vibration energy is called regenerative suspension system. Only 10-20% fuel energy is used for vehicle mobility. One of the important losses is the energy dissipation from the vibration of suspension system.

The specialized design of linear electromagnetic generator, which generates power from the relative linear motion between magnets and coils. The second category is to convert the linear suspension vibration into oscillatory rotation and use rotational permanent magnetic DC or AC generators to harvest energy. These mechanical mechanisms include rack and pinion. The rotary shock absorbers have larger energy density. The bidirectional oscillation will cause large impact force, backlash and friction in the transmission system, causing fatigue or even failure. In early prototype of regenerative shock absorber based on oscillatory rotation generator rack teeth were worn out and broken quickly due to large impact force. A typical regenerative suspension system is as shown in fig-1.

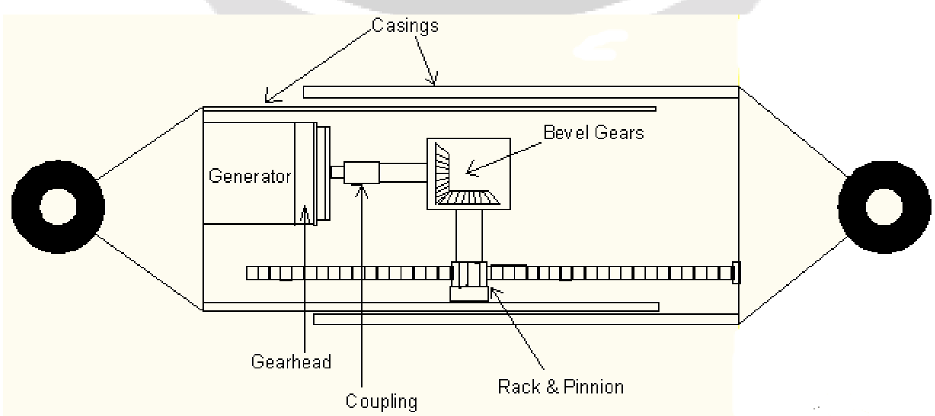

Fig -1: Schematic of shock absorber

1.1 Principle of Motion Rectifier

Shock absorbers are installed between chassis and wheels to suppress the vibration, mainly induced by road roughness, to ensure ride comfort and road handling. Conventional regenerative shock absorbers translate oscillatory vibration of suspension into bidirectional rotation, using a mechanism like ball screw or rack pinion gears. A motion rectifier was developed to commutate oscillatory motion. The motion rectifier functions with two working modes positive and negative mode. The key component of motion rectifier is one-way rollers that transmits rotation only in one direction and divide the motion in two different routes.

The mechanical motion converter with two rollers can be similar to a full-wave voltage converter using a center-tapped transformer and two diodes. It converts the irregular reciprocating vibration into the regular unidirectional rotation. The system inertia is equivalent to the electrical smoothing capacitor in series with the electrical load. When the direction of the motion changes relative velocity between the driving part and driven part also changes. Which is caused by backlash, would be much smaller so that the impact forces would be much smaller. In this way, the reliability would be improved.

1.2 Working mechanism

The vehicle moves over the speed breakers, at height resulting in increase in kinetic energy. This kinetic energy can be harvested by using rack and pinion arrangement in regenerative suspension system. In this system, the linear moment of rack is obtained because of the compression and expansion of suspension spring. The rack and ratchet gears give a positive motion especially compared to the friction drive. The shaft is connected to driven gear with ratchet-wheel type mechanism. This result in rotation of a geared shaft loaded with recoil springs. The output of this shaft is coupled to a dynamo (generator) to convert rotational energy into electricity with help of bevel gears. A vehicle loaded with 1,000 kg going up a height of 10 cm on such a rough road produces approximately 0.98 kilowatt power.

2. LITERATURE REVIEW

The research about energy recovery from vehicle suspensions began more than ten years ago, first as an auxiliary power source for active suspension control, and later also as energy regenerating devices in their own accord. During the past ten years, energy recovery from vehicle vibrations has achieved great commercialization success in hybrid or electric vehicles. Some earlier efforts to recover energy from suspension are-

Zhongjie Li et.al [1] has presented innovative design of regenerative shock absorbers, which helps to reduce impact forces and improves energy harvesting efficiency. It consists of unique mechanism called as mechanical motion rectifier. It converts oscillatory vibration into unidirectional rotation of generator. Shaiju M. B [2] described partially use energy stored in the springs for compressed air generation through a single acting positive displacement pump. Zhang Jin Qui et.al [3] reviewed that conventional vehicle suspension dissipates mechanical vibration energy in the form of heat which waste considerable energy. Y. Zhang et.al [4] presented design; modeling and performance study of novel hydraulic pumping regenerative suspension on an energy recovery unit and a hydraulic actuator. It can harvest energy from suspension vibration; in addition variable damping force can be achieved by controlling electrical load of energy recovery unit. Martande S. et.al [5] presented that Shock absorbers are a critical part of a suspension system, connecting the vehicle to its wheels. The need for dampers arises because of the roll and pitches associated with vehicle and from the roughness of roads. Thus focuses on to develop new correlated methodologies that will allow engineers to design components of shock absorbers by using FEM based tools. Bhoite R. et.al [6] describe that regenerative shock absorber is a type of suspension system that converts parasitic intermittent linear motion and vibration into useful energy, such as electricity. This energy was used to charge the battery and this stored energy was used for different vehicle accessories like power window, lights and air conditioner etc. This energy was applicable in most of the military vehicles, race automobile and maximum suspension systems.

Sethu P S et.al [7] described regenerative braking systems become increasingly popular, recovering energy that would otherwise be lost through braking. The system was 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. Analysis was performed in CFD and values are determined.

Suda Y. et.al [8] studied consumption of fuel has been an important consideration since the beginning of the transportation facility. The system design was done considering the actual measured data on a goods vehicle at various road and traffic conditions in city, highway and off-road for both laden and un-laden applications.

Lei Zuo et al[9] presented a comprehensive assessment of the power that was available for harvesting in the vehicle suspension system . The results suggest that road roughness, tire stiffness and vehicle driving speed have great influence to the harvesting power potential, where the suspension stiffness, absorber damping, vehicle masses are

insensitive. At 96 km/ hours on good and average roads 100-400 watts average power was available in the suspensions of a middle size vehicle.
Robert A et.al [10] studied the energy consumption of passive and active suspension of car under the conditions that vehicle speed was 20 m/s, road roughness was class C, the simulation time was 20 sec, indicated that energy consumption of passive suspension is 651 kJ, while 645 kJ for active suspension which decreased the RMS of sprung mass acceleration by 50%. Theoretical results show a maximum of 10 % fuel efficiency can be recovered from vehicle suspension system by implementing regenerative shock absorbers.
Li et al [11] based on the rack–pinion mechanism scheme proposed; mechanical motion rectifier (MMR) to convert the oscillatory vibration into unidirectional rotation of the generator and this prototype's regenerative efficiency was more than 60% at high frequency excitation, which was much better than previous one. Two over running clutches and a planet gear mechanism to drive a generator, which can realize the similar function. The rotary energy harvesting absorbers translate the up and down suspension vibration into the bi-directional oscillation of the electrical generation and produce electricity.

3. FINITE ELEMENT ANALYSIS OF RACK & PINION SYSTEM

It is a computerized procedure for analysis of structures. Analysis can be performed on the structure shown in fig-2 and represented using the known properties of geometric shapes i.e. finite elements. A complex region defining a system is discretized into simple geometric shapes. The element material property and governing relationships are considered over these elements and expressed in terms of unknown values at nodes. An assembly process, considering the loading and constraints, results in the set of equations. The solution of these equations gives an approximate behavior of the system.

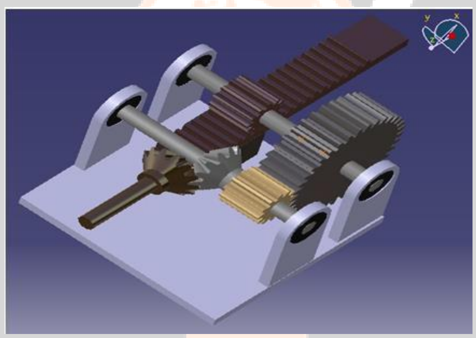

Fig -2: Assembly of components

3.1 Meshed model of the assembly

It consist of defining scalar parameters, model generation, element types, and various material properties, mesh sensitivity analysis and loading condition. The pre processing consists of all information about working condition about part and its environment.

Table -1: Meshing details

Element type	Tetra
Element size	2
Nodes	191479
Elements	102840

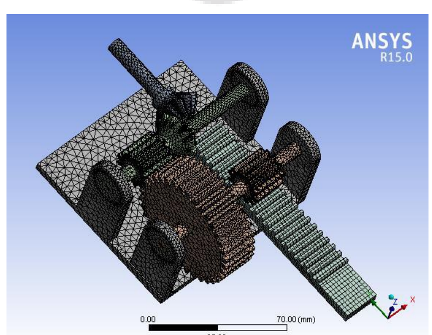

Fig -3: Meshed model of rack & pinion system

Table -2: Material properties of component

Material	Material Properties				
	Density (Kg/m^3)	Young's Modulus (MPa)	Poisson's Ratio	Bulk Modulus (Pa)	Shear Modulus (Pa)
Structural Steel	7850	2.84E5	0.3	1.6667E11	7.6923E10

3.2 Simulation results

Stress analysis

In this analysis von misses stress distribution is calculated as it is used to find plastic deformation for materials such as metals. The von Misses Criterion is used to estimate the yield point of materials. The von Misses criterion states that failure occurs when the energy of distortion reaches the same energy for failure in uni-axial tension. If von misses induced in material is more than strength of material then the design will fail.

Modal Analysis

It is a formalized method for identification of natural frequencies and mode shapes of structures. It utilizes dedicated modal test equipment, and requires a formalized procedure for disturbing e.g. rapping, the structure into motion, and then recording the distribution of the resulting motions throughout the structure. The end results of a modal test are the various natural frequencies, mode shapes of the structure. The results are subsequently displayed as impedance plots and mode shapes (possibly animated). In this project by using modal analysis first the fundamental frequencies for the rack & pinion system are calculated.

Table -3: Different modes with their frequencies

Mode	Frequency
1	708
2	1332
3	1657
4	1689
5	1814
6	2460
7	2519
8	2064
9	3709

Vibration analysis

Analysis of vibration modes is a critical component of a design. Inherent vibration modes in structural components systems can shorten equipment life and cause premature unanticipated failure often resulting in hazardous situations. The detailed vibration analysis is required to assess the potential for failure or damage resulting from the rapid stress cycles of vibration.

The vibration analysis is carried out with respect to harmonic analysis to find out failure due to resonance at fundamental frequencies. Harmonic analysis is used to determine the steady state response of a linear structure to loads that vary sinusoid ally with time. It helps to verify whether the design will successfully overcome fatig ue and harmful effects of forced vibrations. In this analysis all loads as well as the structure response vary sinusoid ally.

Displacement of components according to the fundamental frequency is to displayed in mode shape. As the displacement is in microns it is very minute that it cannot affect body shape to break. Frequency response for the shaft is obtained because more stress is observed at this region. To check the design feasibly it is necessary to check these parameters. A harmonic analysis is used to calculate response of structure to load over frequency range and obtain a graph of displacement versus frequency. Maximum displacement takes place at 2467.7 Hz which is of 1.5 ×10-4 mm. This displacement is negligible hence the design is safe.

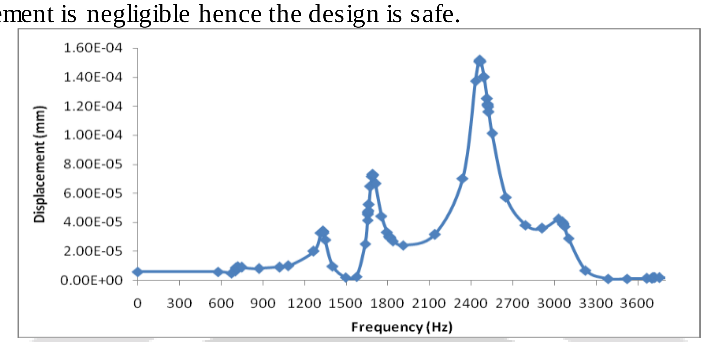

Chart -1: Graph between displacement &frequency

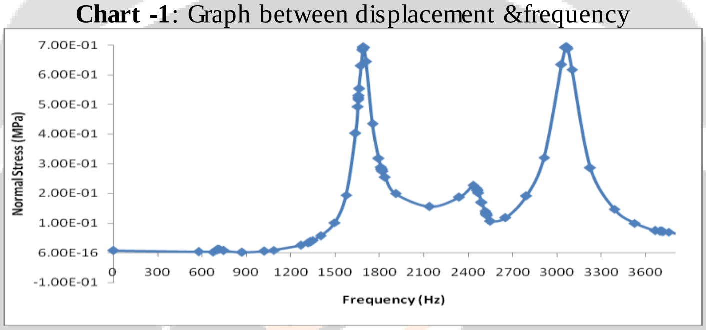

Chart -2: Graph of Normal stress & frequency

From the chart-1 it is concluded that maximum displacement peak is at 2467.7 Hz. The chart-2 depicts that the stress developed at 2467.7 Hz is lower than the material ultimate tensile strength (270 MPa) limit for the acceleration of 1g force in vertical direction. This shows that the design is safe to work at this frequency ranges.

4. MANUFACTURING OF RACK & PINION SYSTEM

The gears are assembled as closure as possible so as to make a compact model. The whole assembly is welded by supports on a plate to give it a stiffer platform. The pinion and the gear are mounted on a shaft first and then they are welded with supports to the platform as shown in fig-4.

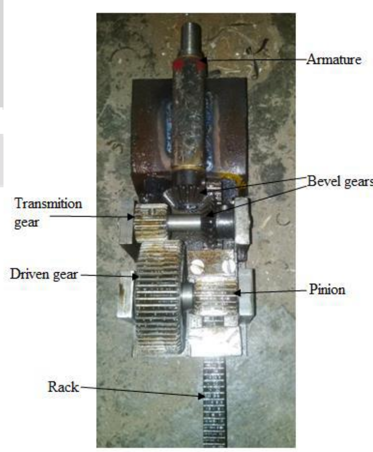

Fig -4: Working assembly

Testing is performed by switching on the motor and the rpm are controlled by dimmer. The rod is moved back and forth due to which, the gear assembly to rotate. Pawl and ratchet mechanism rotates driven gear in one direction. In turn the generator motor rotates and the power is generated. A multi meter is connected to the generator motor outputs for measuring the current & voltage produced which is recorded. The set of readings are to be taken at different rpm of motor which gives different value of current and voltage in multi meter.

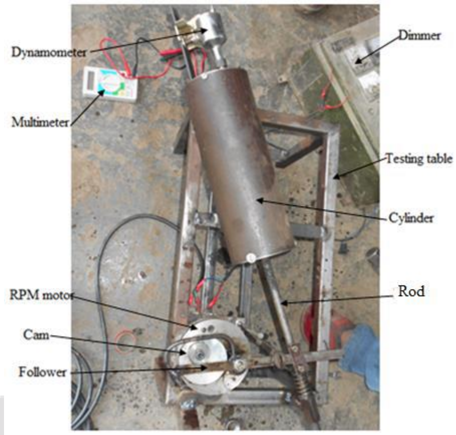

Fig -5: Testing setup

4. RESULT & CONCLUSIONS

On 100 rpm of motor 4.01 V voltage & 0.6533A power produced. By increasing the motor rpm using the dimmer there is change in output. On 120 rpm there is 4.44 V & 0.716 A current. But motor rpm are to be constrained below 250, because above this rpm system will get extra vibration while testing.
The energy wasted in the form of vibration is utilized and electricity is produced.

Different from conventional shock absorber, regenerative shock absorber can utilize the relative motion of shock absorber and convert it into electricity and the energy can be stored in battery for later use.

The experimental results indicate that advantage of motion rectifier is more important, further more the feasibility of this principle and prototype is verified by experimental test.

By applying regenerative shock absorber, the heat waste into environment can be reduced and at the same time fuel efficiency of vehicle can be improved.

With improvement of technology, regenerative suspension may become one of promising trends of vehicle industry.

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