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Regenerative Suspension System for Motorcycles

Amey Konde[1], Aditya Pandey[2], Sarvesh Gandhi[3], Rushikesh Giri[4]

[1,2,3,4] *UG. Student, School of Mechanical Engineering, Dr. Vishwanath Karad's MIT World Peace University, Pune, India*

Abstract - *Automobiles have shock absorbers to damp out the vibrations and shocks generated due to roughness of the roads. However, in conventional shock absorbers energy gets dissipated through dampers in form of heat and this energy is not used or regenerated in any way.*

Regenerative Suspension System provides a means for recovering or regenerating the energy dissipated in conventional shock absorbers. A device which can recover this kinetic energy that relates to the vertical motion of an automobile suspension which is relative to the frame of the vehicle when it is traveling on a roadway, the device comprises of: energy conversion or regenerative means for converting the energy relating to the vertical motion of the vehicle frame relative to the vehicle suspension to a form of energy which can be stored for a later use in powering vehicle systems.

Road vehicles can waste a significant amount of generated energy in undesirable vertical motions or shocks that are induced by road bumps and much of that is dissipated in conventional shock absorbers as they dampen the vertical motions.

This project aims to determine the effectiveness of efficiently transforming this energy into electrical power by using an optimally designed regenerative electro-mechanical system. In advantage, the electrical power can be used to recharge batteries or other energy storage devices rather than be dissipated.

Key Words: Suspension, Dampers, Energy Conservation, Energy Regeneration, Regenerative System, Rack and Pinion.

1. INTRODUCTION

World-wide demand for oil is increasingly straining the available supply from the resources. The need for more oil means higher prices and increasing pollution. With fuel prices on the rise, people and businesses are looking for environmentally sound and friendly solutions. New technologies have emerged to combat rising fuel prices and decrease pollution.

The job of a car suspension is to maximize the contact patch between the tire and the road to provide steering stability, good handling and ensure the comfort of the passengers in the vehicle. Even freshly paved highways have subtle irregularities that can interact with the wheels of the vehicle. These irregularities apply forces to the wheels.

According to Newton's laws of motion, all the forces have both magnitude and direction. A bump in the road causes the wheel to perpendicular to the road surface. The magnitude depends on whether the wheel is striking a giant or a tiny irregularity. Either way, the car wheel experiences a vertical motion or shock as it passes over any road imperfection. Without an intervening structure or suspension system, all the wheel's vertical energy due to shock is transferred to the frame. Since the frame is moving in same direction so in such a situation the wheels can lose contact with the road completely. Then, under the downward force of gravity, the wheels can slam back into the road surface losing the driving stability. Most automobile engineers consider the vehicle dynamic from two perspectives - Ride and Handling.

Ride is a car's ability to smooth out an irregular road. Handling is a car's ability to safely accelerate, brake and corner in motion. These two characteristics can be further described in three important principles- road isolation, holding, and cornering.

What is needed is a device which will conserve the kinetic energy of suspension movement. A device for recovering the kinetic energy related to the vertical motion of the vehicle is needed, the device comprise of:

- Energy conversion means for the energy relating to the vertical motion of the vehicle frame relative to the vehicle suspension to a form of energy which can be stored on the vehicle for later use in powering vehicle systems and electronics.
- A vehicle suspension kinetic energy recovery system generates useful energy from the up-and- down motion of a vehicle suspension caused by roadway irregularities as the vehicle travels down the roadway.

2. AIM AND OBJECTIVE

This project aims to provide a mechanism that will be able to convert the mechanical energy available in automobiles efficiently into electrical energy. The power generated using this mechanism will be efficiently stored and it will be utilized for simple operations in a conventional vehicle such as power sliders, air conditioning, headlights, horn, and other simple operations which do not require much energy. While in electric vehicles this stored energy can be used to charge the batteries.

The objective of this project is to design a mechanism that can be used to generate power by using the upward and downward movement of the shock absorber. Since the generator produces energy only when it moves unidirectionally, so to fully utilize the movements of the shock absorber a mechanism is to be designed which can derive power from the upward and downward rotation of the pinion.

3. LITERATURE SURVEY

The research about energy recovery from vehicle suspensions began more than a decade ago, first as an auxiliary power source for active suspension control, and later as an energy regenerating device in their own accord too. During the past some years, energy recovery from shock absorber vibrations has achieved great commercialization success in hybrid or electric vehicles. Some efforts to recover energy from suspension of are interest are-

1. Xueying Lv in his research on regenerative suspension systems studied the Hydraulic energy-conversion shock absorber. With the wide application of piezoelectric crystals and intelligent materials, energy-regenerative shock absorbers are mainly divided into two categories, which are hydraulic and electromagnetic. How to reduce the overall energy consumption was a suggested important problem. In addition to this, the matching problem of hydraulic energy-supply suspension system along with the vehicle power system should also be taken in consideration.
2. Ravindra Bhoite made a laboratory prototype of a Regenerative shock absorber. The model was not mountable on an Automobile. A full wave bridge rectifier was used to double the output of the system. This suspension system will be mostly useful in heavy compressed vehicles, fire brigade trucks, milk trucks, and those having high requirements for electricity inside it. From the result table we are observed that for a small number of teeth of gear we get the maximum voltage and current.
3. Zhen Zhao used a Piezoelectric harvester in which the upper end of the harvester is connected to the vehicle body and the lower end is connected to the wheels of the vehicle. In this the motion conversion component is composed of a ball screw shaft and nut, and the energy conversion component is composed of an outer stator ring and an inner rotator ring. Rectangular magnetic slabs of same sizes are uniformly mounted in the circumferential direction on the inner circular surface of the stator ring. Now the piezoelectric patches are embedded in between the magnetic slabs and the stator ring have the same rectangular dimensions as that of magnetic slabs. The rotor ring is connected to the ball screw through a spline structure in order to achieve torque transmission. On the outer circumference of the rotor ring, a set of magnetic slabs with the same size as that of the piezoelectric patches are placed along the circumferential direction. Through this structure, whenever the rotor rotates, a periodic magnetic force is generated between the stator ring and the rotor ring, and the magnetic force acts on the piezoelectric patch along the polarization direction, hence harvesting electrical energy.
4. G.P. Dhalwar developed a rack and pinion mechanism to transfer power, the power was transferred with the help of bevel gear of whose driven gear was directly connected to the shaft of the motor. An analysis and various tests were performed on the system. The results showed that on 100 rpm of motor 4.01 V voltage & 0.6533A power produced. By increasing the motor rpm using the dimmer there is a change in output. On 120 rpm there is 4.44V & 0.716A current. But motor rpm is to be constrained below 250, because above this rpm system will get extra vibration while testing. Thus, the energy wasted in the form of vibration is now utilized and electricity is produced.
5. Rajat. G. Jadhav manufactured another lab project of a Regenerative suspension system. The mechanism consisted of a rack and pinion mechanism. Project was made of simple plastic gears and was not a practical project with mounting issues in an actual vehicle.
6. Bharani Chandar .J developed a mechanism consisting of rack and pinion mechanism. The Rack and Pinion were made using a 3D printer. The external casing which encloses the component is made up of acrylic plastic by molding process. The rack is protected by a retractable rubber casing to protect it from external agents like dust, moisture, and direct sunlight to prevent it from degradation over time and usage. The current and voltage curves rise uniformly with gradual increase in stroke length. Therefore, the extent of compression in the suspension affects the generation of power in the component. Thus, it can infer from the research done that the diameter of the pinion, the travel length of the rack and the teeth profile needs to be designed in such a manner that the maximum effort is produced by providing minimal input, in order to produce the sufficient power for desired usage.

4. METHODOLOGY

This project is an experimental research study. It focuses on the conversion of the vibrations or jerks that are generated from the movement of a vehicle on road using a Rack and Pinion mechanism. This project revolves around the concept of utilizing the work done by the shock absorbers when a vehicle is moving.

This project works on the principle of Conversion of Kinetic energy of the Shock absorber into Electrical energy. The energy dissipated in the form of heat should be compensated by producing some energy through the movement of the Shock absorbers.

The objective is to use a Rack and Pinion mechanism to transfer the motion of the shock absorber to the shaft of the Generator using a compound Gearbox. The power transferred to the Generator is in Alternating Current form and it needs to be converted to Direct current by using the Rectifier, which will allow the flow of current in only one direction. Thus, the power generated can be stored in Capacitor banks or it can be directly used for different applications in the conventional vehicle. This stored power can also be utilized for charging the battery of the electric vehicle.

The objective is not to reduce the amount of Energy dissipated in the form of heat by the Shock absorbers, but to compensate the work done by the shock absorber and the energy dissipated by producing energy without any external work.

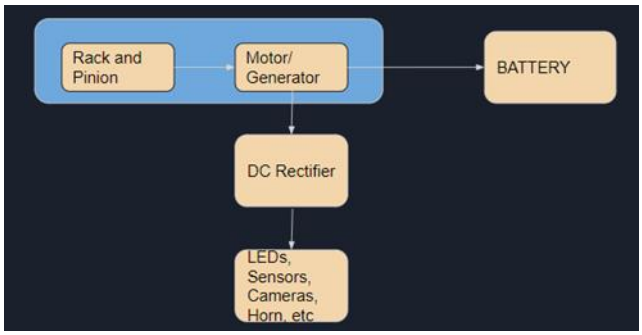

Fig -1: Flow of Solution

5. DESIGN AND COMPONENTS

5.1 Basic Design

The Design consists of the Driving part and the Driven part. The driving part consists of a Rack and Pinion mechanism. The two Spur gears acting as pinion are connected linearly while facing opposite to each other on a customized shaft. At the end of the shaft is a Spur gear which gets its motion due to the rotation of the shaft.

This spur gear rotates another spur gear which is directly connected to the shaft of the Generator, this is the Driven part.

5.2 DC Generator

An electric generator is a device that can convert mechanical energy to electrical energy in a competent manner. A generator forces charge (carried by electrons) to flow through an external electrical circuit. It is equivalent to a water pump, which causes water.

to drift (but it is not able to generate water). The source of mechanical energy will be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, a wind turbine, an internal combustion engine, a hand crank, compressed air or some other source of mechanical energy. The conversion of electrical energy back to mechanical energy is done by using an electric motor. Motors and generators have numerous similarities. Many motors can be mechanically driven to generate electricity.

6. COMPONENT CALCULATIONS

6.1 Assumptions

Average Initial Displacement = 0.5663 inches/sec of vehicle travel
∴ Average attainable velocity = 0.5663 inches/sec = 14.13 mm/sec
System is designed according to following parameters:
Average Rack velocity = 14.13 mm/sec Average RPM required = 24 RPM
GEAR 1: Angular velocity = W_1
Pitch Circle Diameter = $2r_1$
GEAR 2: Angular velocity = W_2
Pitch Circle Diameter = $2r_2$
GEAR 3: Angular velocity = W_3
Pitch Circle Diameter = $2r_3$

6.2 Calculations

Specifications of Alternator / DC Generator: 12V DC @ 24 RPM
V_1 = 14.13 mm/sec: r_1 = 26mm Since, $V_1 = W_1 r_1$
W_1 = 0.54 rad/sec
W_1 = W2
∴ $W_2 r_2 = W_3 r_3$
W_3 = (2 * 3.14 * 24) / 60 = 2.512 rad/sec
∴ r_2 / r_3 = 2.512/0.54 = 4.65
Let, d_2 = 108.5 mm
∴ d_3 = 108.5/4.65 = 23.4 mm

6.3 Gear Calculations:

GEAR 1:
PCD = 52 mm
Let's consider the standard module for the gear, module = 2
∴ No. of Teeth = 52/2 = 26
Face width = 10 * module = 10 * 2 = 20 mm Material for Gear 1 is EN-8 (Steel)

GEAR 2:
PCD = 108.5 mm
Let us consider the standard module for the gear, module = 1.5
∴ No. of Teeth = 108.5/1.5 = 67
Face width = 10 * module = 10 * 1.5 = 15 mm Material for Gear 2 is EN-8 (Steel)

GEAR 3:

PCD = 24 mm
Let us consider the standard module for the gear, module = 1.5
∴ No. of Teeth = 24/1.5 = 16
Face width = 10 * module = 10 * 1.5 = 15 mm Material for Gear 3 is EN-8 (Steel)

6.4 Rack Calculations:

Length of Track:
The Length of track should be equal to the Total vertical travel of the vehicle Suspension. In our Project we consider the displacement of the Front fork of a Motorcycle = 12 inches

Number of Teeth on Rack:
Total vertical travel of wheel = 12 inches Considering the PCD of an imaginary gear = 12 inches
Diameter of that gear = 2.05 inches i.e. 52 mm

We know the module of Rack and Pinion pair, m = 2 mm

∴ No. of teeth on rack = 26 Teeth Material used for Rack is En-8 (Steel)

7. FINAL DESIGN ASSEMBLY, WORKING AND ANALYSIS

7.1 Components

GEAR 1:
This is a single unit in which gears are made on one side. These gears mesh with the rack and this converts the linear motion into the rotational motion.

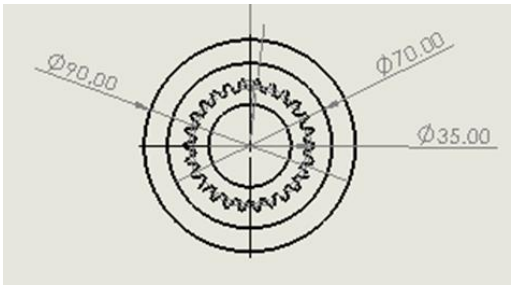

Fig -2 (a): Top View of Gear 1

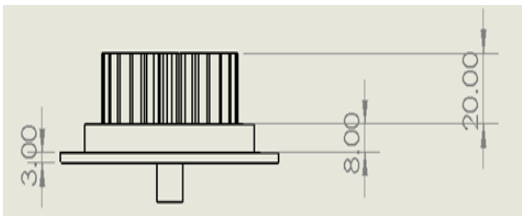

Fig -2 (b): Side View of Gear 1

GEAR 2:
This is the Gear which is connected at the end of the shaft and is in mesh with the Driven Gear connected to the shaft of Generator.

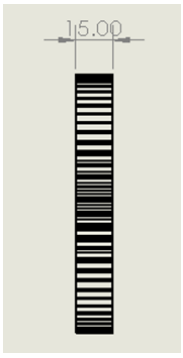

Fig -3 (a): Top View of Freewheel

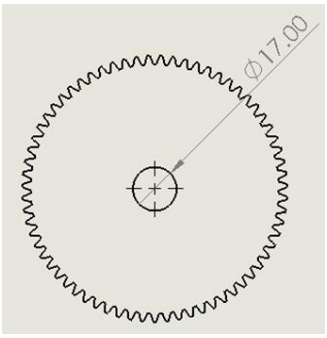

Fig -3 (b): Side View of Freewheel

GEAR 3:
This is the Gear directly connected to the shaft of the Generator.

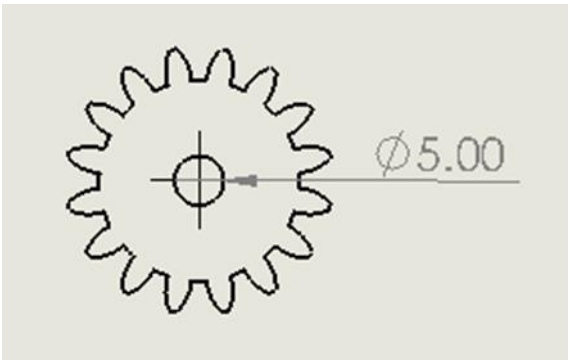

Fig -4: Gear 3

Customised Ratchet Mechanism:
The function of this part is to hold the freewheel with the pinion gear. It becomes one assembly thereafter. Two such assemblies are required. The bottom figure is the shaft on which the above- mentioned assembly is mounted. After mounting the assembly, this shaft rotates in one direction only, no matter what direction the rack moves. A socket type part is added to Gear 1 in order to hold the Pawl of the

Ratchet mechanism.

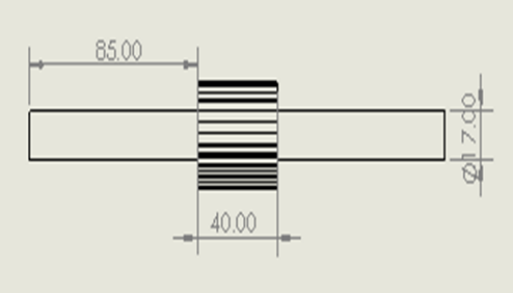

Fig -5 (a): FV of Customised Shaft

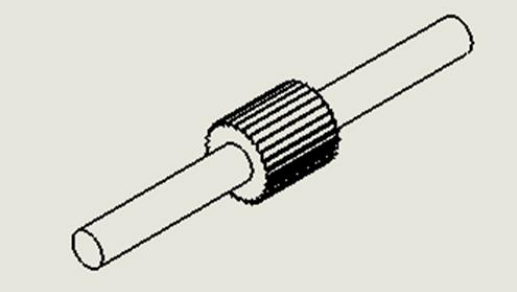

Fig -5 (b): Isometric View of Shaft

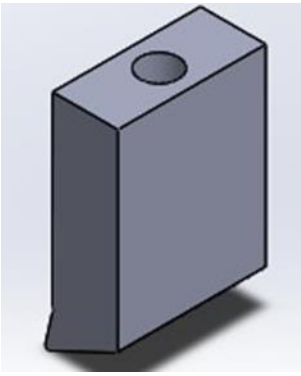

Fig -5 (c): Isometric View of Pawl

7.2 Final Assembly

In the figure below is a SOLIDWORKS model of the project. The red gears depict the Gear 1, green gear is the Freewheel connected at the end of the shaft. The blue gear is the drive gear connected to the shaft of the Generator. The yellow part is the Pawl of the ratchet mechanism. The grey part is the Housing of the whole assembly.

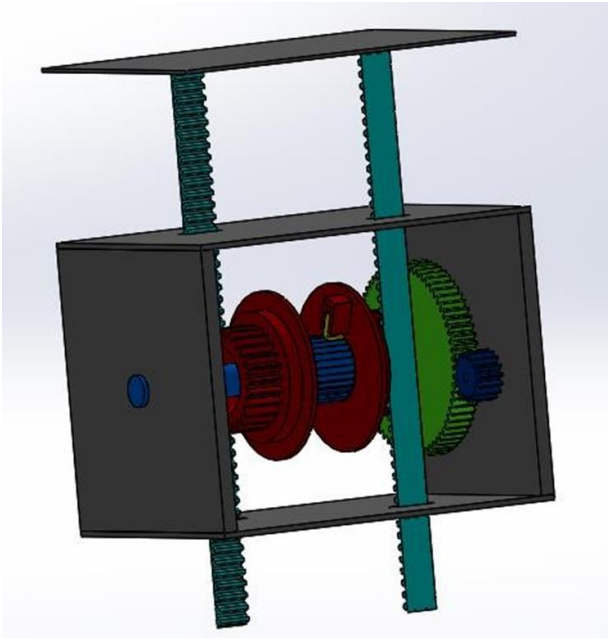

Fig -6: Final Assembly of the Project

7.3 Working

The basic idea of the project is to transfer the linear motion of the shock absorber to the rotatory motion of the Generator shaft to produce Power. This is achieved by the means of a rack and pinion mechanism and a gearbox. Whenever the vehicle will move through a rough road or a bump, the shock absorber will move up and down. Since the upper plate is connected to the shock absorber, it will move the rack along with it. The rack will then rotate the gears which are mounted on the shaft which converts the linear motion into rotational motion. The generator will produce power only when its shaft will rotate in a single direction. Let us say power will be generated when the shock absorber will move downwards, so the chance to generate power in the upward cycle of the shock absorber is wasted. To overcome this drawback the project includes a Ratchet type mechanism. The shaft on which the pinions are mounted have been customized to make a Ratchet wheel. A socket is made for the pawl and spring on the back of each pinion gear. Pawl is connected to a spring which is fixed to the socket at the upper end, the angle of the Pawl is designed according to the tooth profile of the customized ratchet. Whenever the rack will move downwards, one pinion will move clockwise while the other one will move counterclockwise. Due to its angle the pawl of one of the pinions will interfere and rotate the shaft while the other pawl on the other pinion will simply slide over the teeth of the ratchet shaft while rotating with the pinion. Vice versa

will happen in the case when the rack will move upwards. This mechanism assures that the Power is generated for each cycle of the Shock absorber motion. The shaft when rotated will provide unidirectional rotation of the Freewheel for both the cycles of the Shock absorber. The freewheel in turn will rotate the Driven Gear, which is attached to the shaft of the Generator, and hence Power will be generated.

7.4 Analysis of the Project

Load test of the project is performed. The maximum load bearing component in the assembly is the customized shaft. Load will be applied only when the vehicle goes into Pitching motion, and hence due to weight transfer, the load on the front wheel of a motorcycle or two-wheeler is 800 N.

LOAD TEST RESULTS:

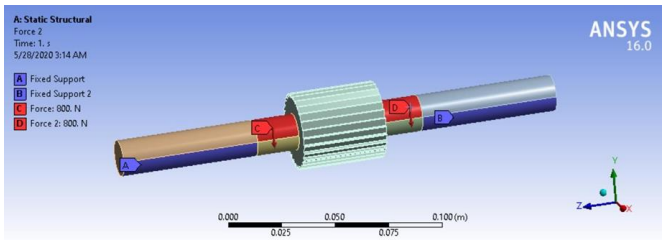

Fig -7 (a): Stress Induced

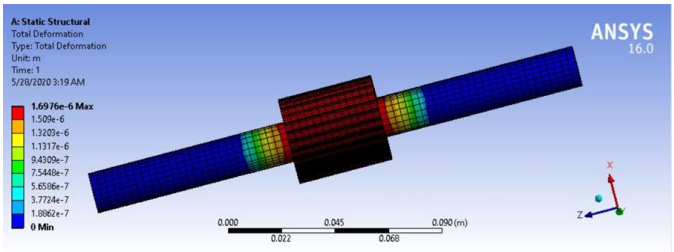

Fig -7 (b): Total Deformation

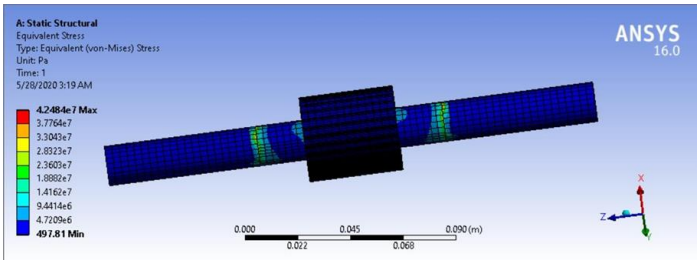

Fig -7 (c): Equivalent Stress

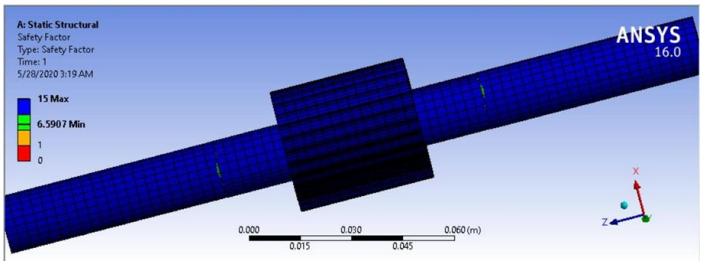

Fig -7 (d): Factor of Safety

8. ELECTRONICS

The electronics part is the other core element of the project. This part is important because power production depends upon how well the Electronic system is equipped within the project. The electronics can be further divided into two categories.

1. Power producing unit
2. Data acquisition

8.1 Power Producing Unit

The power is fabricated from a simple geared motor which is being used as a DC generator in this case. The motor has the following specifications:
Generator Output: 6V - 20V Current Output: 0.5 - 1 Amp
RPM usage: 20 - 30 RPM

Motor Selection:

Generally, there are various motors available in the market that can produce power. However, the current project has some specific requirements that must be satisfied.

- As the rpm of the mechanism is very low, so to utilize the maximum of the energy available in the suspension movement, such an rpm is selected that can easily give a decent output voltages level, say 15-20 volts.
- The size should be as small as possible.
- It should have the facility of mounting additional accessories such as gears or belts on the shaft.

The next important part in the power generation is the storage or usage. Since the power produced is always varying with time, so using those small values of power does not prove to be useful nor does that make any sense. Hence, a system must be developed that can accumulate such power and there after it can be used. It is just like filling a tank with small drops of water and then as the tank is filled up to the top, the water is again utilized for heavy purposes.

The system uses a capacitor bank for that. Very large capacity capacitor 15000uF 63 V are used for this. The capacitors are very big because:

- It can hold a large amount of charge.
- The rate of discharging is small so that all the power is not dissipated in a spur of time.

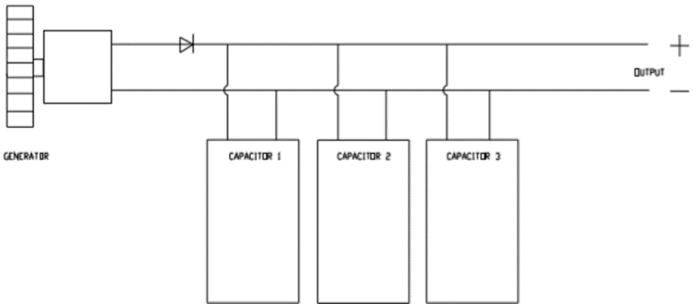

Fig -8: Power Producing Circuit

8.2 Data Acquisition Unit

The whole project started with mere observations, observation being watching the suspension going up and down movement. As the idea of utilizing that power available in the suspension system is proposed, there starts the process of data acquisition. It means that if the observation really meant anything. In this system data is acquired about:

- How much movement of suspension is possible?
- How fast that movement can be?

9. RESULTS AND CONCLUSION

The comprehensive findings from literature survey indicated that the typical dissipation rates in a vehicle suspension were round about 5 to 20 (W) per vehicle damper, however, approximately 50 (W) could be dissipated for a vehicle traversing a road classified as 'poor'. Overall, it appeared that the power dissipation generally increased for an increase in vehicle velocity and increased for an increasingly degraded road surface condition.

This project was designed to develop a mechanical regenerative suspension system. The objectives of this project were to develop the system which would harvest the energy in the suspension system and also be simple for construction and maintenance. It was also necessary to check whether output generated from the system is worth the cost of design and implementation.

This project also has certain limitations such as it has certain space constraints. The system should acquire as less space as possible and should not hamper the movement and the damping capacity of the suspension system. The system which we have designed in this project is suitable for the vehicles where adequate space is obtainable for accommodating the parallel suspension and regenerative system.

10. FUTURE SCOPE

We are in the era where the companies are keen on making systems compact by using advanced direct conversion devices. Here in our suspension system, we can place the regenerative system inside the damper, which will lead to a compact design and lesser load on suspension. We can completely replace the conventional damper by mechanical generator and the damping can be provided by the resistance to motion by the generator itself, which will lead to total vibration energy conversion and better results. In the future, work would consist of a redesign of this model to see exactly how much data we may be missing with the assumption that we made with the constraints of low price, weight, and capacity. Despite all the assumptions, we still can conclude that this product can be very marketable and that the demand is extremely large which means this is a viable design that can generate a high return on the investment.

- Such suspension systems can be designed for heavy vehicles, thus increasing input torque to the regenerative system, and ultimately output of the generator.
- More suitable and compact mechanisms to enhance efficiency of the system.
- Various government departments can take up an initiative to implement these power humps on a large scale in the market.
- This has a huge scope everywhere provided the resources are channeled well.

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BIOGRAPHIES

Mr. Amey Konde
"U.G. Mechanical Engineering
Dr. Vishwanath Karad's MIT World
Peace University, Pune, India"

Mr. Aditya Pandey
"U.G. Mechanical Engineering
Dr. Vishwanath Karad's MIT World
Peace University, Pune, India"

Mr. Sarvesh Gandhi
"U.G. Mechanical Engineering
Dr. Vishwanath Karad's MIT World
Peace University, Pune, India"

Mr. Rushikesh Giri
"U.G. Mechanical Engineering
Dr. Vishwanath Karad's MIT World
Peace University, Pune, India"