Design and Simulation of Regenerative suspension system

Prof. Smitha B.S[1], Hibel Hussain[2], Johnjo Josmon[3], Muhammed Nihal[4], Rohith. V[5]

[1]*Professor, Automobile Dept – New Horizon College of Engineering, Bangalore, India*
[2,3,4,5]*Final year student, B.E – Automobile, New Horizon College of Engineering, Bangalore, India*

Abstract - *With the expanding population the energy utilization has expanded which makes the necessity for clean energy significant, presently like never before. The vehicle area is the greatest supporter of this utilization and ought to thusly be thought about when searching for ecologically cordial arrangements. Most of fuel energy in street bound vehicles of today is disseminated and is accordingly never used. For a traveller vehicle going at 13.4 m/s it is tracked down that 200 W worth of energy is lost in the vehicle's suspension framework. The reason for this work is to examine and assess existing techniques for energy recovery from vehicle suspension systems to distinguish the most ideal arrangement. To end with, the report will propose numerical models for simulation of the particular system. The paper focuses on the general design and simulation of the regenerative suspension system, drive modes types of regenerative suspension system, speed bump generating electricity, MR electromagnetic regenerative damper, the future of regenerative suspension system. It also contains the experiment carried out by us. This includes design, calculation, 3D model, Simulink model, simulation of those models, results and comparison study.*

***Key Words*: Regenerative suspension system, energy, vehicle, design, simulation, electromagnetic, Simulink model.**

1.INTRODUCTION

The automobile industry is producing vehicles that are more energy efficient and electrified. Suspension has been widely established as a crucial component in the world of vehicles. To decrease vibration, normal suspension releases vibration energy as waste heat. For utilizing this energy, regenerative suspension system is used. It will convert the vibrational energy into electrical energy.[4] Perhaps the greatest issue confronted today with regards to supportability is the energy emergency which has prompted extraordinary problems in the advancement of energy productive and the ecological arrangements of regular day to day existence. Probably the biggest space of concern is the vehicle area which has effectively seen incredible improvement lately. When seeing street bound vehicles just 14 - 30 % of the fuel energy is utilized for the versatility of the vehicle's vibrations distribute a large portion of the burned-through energy into heat. As a result, collecting a portion of the energy that is dispersed is one way to reduce energy consumption.[3]

This is when we came up with an idea to utilize the motion that is created in shock absorber and to convert that motion to generate electrical energy. Which then can be used to do the basic tasks which require electric current in an automobile i.e., starts up the ignition system of your vehicle, keeps the energy system of your vehicle sustainable. These are the tasks done by a battery, so the energy utilized from suspension system is used to recharge the battery.

As of late, regenerative shock absorber systems grabbed the eye of numerous scientists in light of the capacity to gather scattered energy, because of its plausibility and open. The fuel energy use of a vehicle was explained by Lafarge, Cagin, who stated that the fuel energy dissipated to move the wheels accounts for 22.4 percent of the total fuel energy spent, placing it second only to engine heat losses (75.2 percent). Because of uneven or unpleasant roadway conditions, the degree of scattered fuel energy on driving the wheels is expected to increase in general. Unlike a traditional shock absorber, which dampens vibrations with thick damping and converts kinetic energy into heat energy that is then dissipated, a regenerative shock absorber transforms kinetic energy primarily into electrical energy. This harvested electrical energy can be stored in the battery for later use.

The regenerative suspension or shock absorber work as a piece of the dynamic suspension framework to improve the ride and solace execution. The consonant necessary sub control is usually utilized in these applications for availing stable yield force or decreasing vibrations. In view of the preservation of energy guideline, better ride and solace execution coming about because of less active energy or less vibration energy of the suspension framework yields less measure of reaped energy. The unpredictability can be overwhelmed by accepting the control framework which can make a trade-off for both the energy reaping and ride and solace exhibitions. One great idea proposed by Elliott and Zilletti was to use the electromagnetic transducer as either a shunt damper or an energy reaper.

Thusly, the framework can be exchanged between the various functionalities for wanted execution yield. The coupling coefficient increased with the size of the electromagnetic transducer, implying that the framework that solidifies the shunt damper and energy seeker can act admirably as a regenerative shock absorber, notably in the enormous scope transducer.[2] The regenerative suspension or shock absorber trends in upcoming would be:

- Better efficiency in mechanical to electrical conversion.
- Compatibility with vehicle would be high.
- The vehicles would have great power to weight ratio.

2. LITERATURE REVIEW

It is critical to conduct a literature review using a variety of sources such as journal articles, books, articles, and videos. This contains all past investigations conducted by different research projects. The literature review is done because we can use the studies related to our project and implement it. We should have a clear idea about the project we are doing because this helps us to gain knowledge by fully understanding it and complete the project.

2.1 Suspension system

The automotive chassis is directly attached to the axles and is supported by springs. The procedure is carried out to protect the vehicle's body against road shocks such as rapid bounce, pitch, roll, or sway. This may influence the rider's comfort while also adding pressure and stress to the car's frame and body. Suspension system refers to the components that support and execute their functions in the automobile by absorbing road shocks. It contains the springing mechanism as well as different mounting options.

The suspension system consists mostly of a damper and a spring. The springs are actuated by the energy from the road shocks. These oscillations are controlled by dampers, which are also known as shock absorbers.

Principle Involved in Working of Suspension:

The suspension control arms allow the free wheel movement of the wheel from the body. This system supports the vehicle from the road bumps. The springs manipulate the frequency from the road disturbance and bring the vehicle to the stable condition. They also provide damping to the friction. The dampers remove the energy from the road bumps. Together they try to eliminate the loads and provides the vehicle with smooth moving action and also provides stability of the vehicle.

Different Types of Suspension Used in Automobile:

- Dependent suspension
- Independent suspension
- Semi- Independent suspension

Objectives of Suspension System are:

- To prevent road shocks from being transferred to the vehicle;
- To protect the driver from road shocks.
- To ensure the vehicle's stability while in motion.

2.2 Basic design of the regenerative suspension system

The shock absorber in a regenerative suspension system requires three components: suspension vibration input, generator modules, and transmission modules. The transmission receives kinetic energy from the suspension vibration input, which causes the shaft to move in both directions. The transmission module, which is made up of helical gears and a one-way clutch, turns the motor's two-way shaft movement into one-way movement.

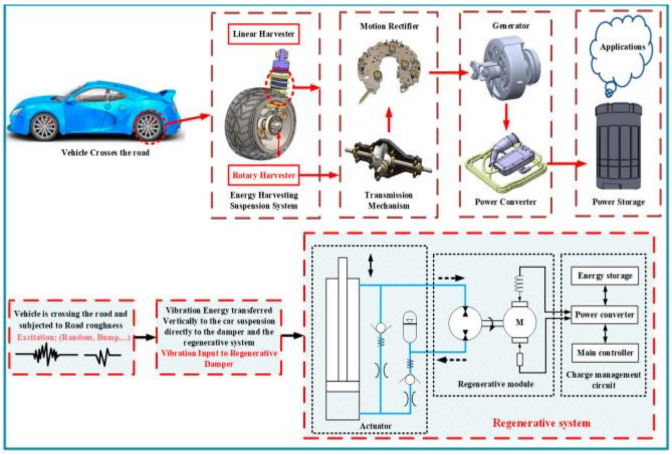

Fig -1: overall scheme of vehicle regenerative suspension system

Electric vehicles use generator modules to generate electricity to operate their electrical equipment. To charge the battery, a DC brushless generator is employed, and the three phase AC electricity is converted to DC via full wave rectification.[4]

Energy loss in conventional suspension system

According to a report released in 2008 by the United States Environmental Protection Agency in collaboration with colleges and firms like as MIT and Ford, only around one-fifth of the fuel energy is turned into mechanical energy, with half of that energy going to drive the automobile wheels. The engine was responsible for approximately 75% of the energy loss (such as heat, pump, and friction losses), but the tyre was responsible for approximately 23%.[4]

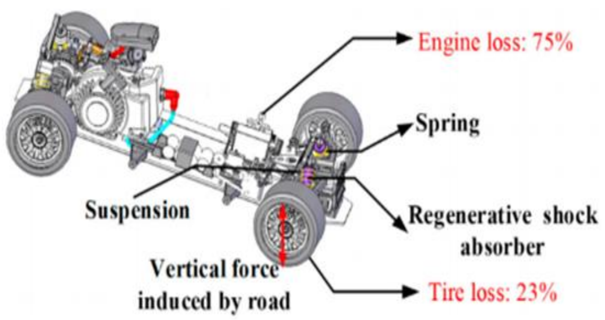

Fig -2: Vehicle energy consumption

Table -1: Major types of the regenerative suspension system[1]

Electromagnetic Regenerative Suspension System	**Mechanical Regenerative Suspension System**
It is based on Faraday's law of electromagnetic induction.	This device converts linear motion into rotary motion.
Dual tube-like components make up the shock absorber. Inside a bigger coil tube, a smaller magnetic tube glides inside.	The flywheel stores rotational energy and uses it to rotate the dynamo, which creates electricity.
The coil is made up of copper coils coiled around a plastic tube, while the magnetic component is made up of ring-shaped magnets separated by magnetically permeable spacers in the shape of ring-shaped magnets	The rack with the pinion rotates exclusively in one direction. Linear motion is converted to rotary motion by the rack and pinion. Chain drive is used to increase the rotating motion. The free wheel's output is connected to a flywheel, which stores K.E. and transfers it to a dynamo, which generates electricity.

2.3 Drive modes types of regenerative shock absorber/suspension systems

These regenerative suspension/shock absorber systems are mainly classified into 3 drive modes; the direct drive, indirect drive and hybrid drive.

Direct drive regenerative shock absorber systems and technologies

Because of its simplified design and quick assembly, a direct drive framework has piqued people's curiosity. Zuo Scully created a 1:1 scale straight regenerative suspension or shock absorber framework with a longitudinal magnet action. A steel exterior shell and an aluminium centre bar were also added to increase the magnetic field output. This type could deliver 2–8 W of power, and it was discovered that additional force could be collected at reverberating frequencies.

Magnet Arrangement Pattern Design

Different magnet designs were presented to further expand the magnetic field force for high yield power. One of the simplest methods is to double the number of magnets, resulting in more appealing transition lines that can be caught in the middle of two layers of magnets where the loops are linked, so increasing the yield voltage. This route has been included in the designs of many analysts since it is both productive and simple to construct. Figure (Fig-3) also shows that in a magnet stack, the magnets are separated by spacers rather than being placed immediately next to each other. [2]

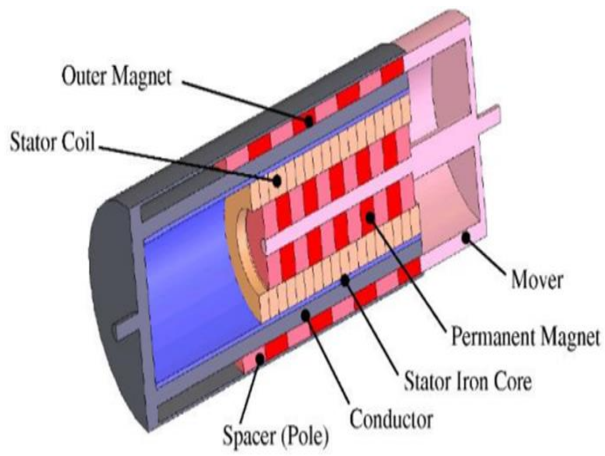

Fig-3: Design of the electromagnetic damper with 2 layers of magnets

Coil Design

Regardless of whether magnetic design is used in the regenerative shock absorber, a few studies have suggested that the coil be planned based on the magnet's path of action. As shown in Figure, Tang, Lin proposed using a four-stage coil in a single magnetic cycle (**Fig-4**). The justification may be seen in Figure (**Fig-5**) where a higher coil stage number results in a greater standardized force. If fewer coil stages are used, more electromotive potential will be counterbalanced.

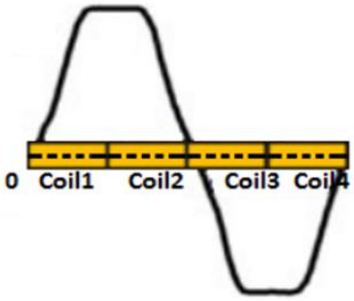

Fig-4: Four-phase coil design

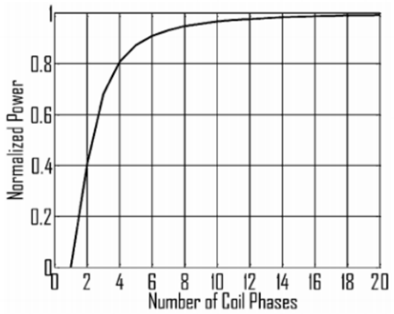

Fig-5: Normalized power vs number of coil phases

Table-2 summarizes the various regenerative shock absorbers using instantaneous driving methods.

Table-2: Summary of the direct drive regenerative shock absorbers

Presenter	**Mechanism**	**Voltage Output (V)**	**Power Output (W)**	**Vehicle Speed (km/h) or Road Excitation Amplitude and Frequency (Hz)**	**Damping Ratio/Harvesting Bandwidth**
Zuo, Scully	Electromagnetic system	10 V	8 W	4 Hz	21 Hz
Tang, Lin	Electromagnetic system	N/A	2.8 W	5 mm at 10 Hz	N/A
Sapi ´nski, Rosół	Combination of MR damper and electromagnetic system	2 V	0.4 W	4.5 mm at 4 Hz	1 Hz

In-direct drive regenerative shock absorber and systems and its technologies

Many attempts are made to increase the coil speed in relation to the magnets due to the load of the magnets and coils. The indirect drive regeneration muffler architecture does not directly convert road excitation into direct movement between the translator and, hence, the stator. All things being equal, it intensifies the data excitation through an assortment of systems and converts the straight movement generally into a rotational movement. The ball screw component, rack and pinion instrument, pressure driven component, pneumatic system, and their modifications are among the many forms of systems offered. Due to the system related rule, the ball screw, rack and pinion, and their modifications are regarded as mechanical movement rectifiers among these instruments. Fluid motion rectifiers are devices that use a hydraulically driven or pneumatically powered framework to impart movement transformation and velocity intensification.

Mechanical Motion Rectifier

Li and Zuo developed an inventive motion rectifier framework, depicted in **Fig-6**, that could convert the muffler's up and down development into one-directional generator spinning. The rack and pinion component assists with changing over and enhance the excitation removal.

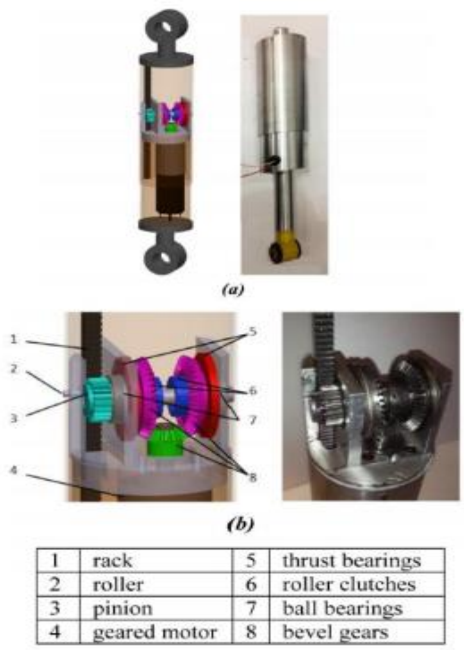

Fig-6. The regenerative damper prototype (a) and the integrated motion rectifier (b)

The bidirectional direct movement to unidirectional pivot amendment is cultivated with the cogwheel and clutch. The analysts performed the trials and recreations, which revealed that the model achieved a high proficiency of 60% and a 15 W power yield when the vehicle was travelling at 15 mph. Li and Zuo led a more thorough analysis of the model's presentation. The 1 / 4 vehicle suspension model was created to simulate the situation where the car was driven on an ISO Class C Street. It was discovered that the movement rectifier can achieve both road comfort and street addressing on a basic car. When travelling at 67.5 mph, a quarter vehicle regenerative suspension with the movement rectifier can produce 60–84 W, which is more than a quarter vehicle regenerative suspension without the movement rectifier.

Unlike previous rack pinion frameworks that employ an electrical generator to provide damping power, this design uses a thick damper in conjunction with the auxiliary rack and pinions at the base to provide damping and gather energy. Regardless of the bundle size, this concept may not be feasible in a real-world application. A ball screw method was suggested by a number of experts, and the schematic is shown in **Fig-7**. Through a ball screw moving along the string, it converts top and bottom motion into rotational motion, just like the rack and pinion architecture. The altered over rotational motion is dual-directional and requires correction because to the up and down motion of the shock absorber. Zhang and Huang combined a regenerative shock absorber framework with a ball-screw component and a DC brushless engine. The analysis revealed that the sine wave street input can yield the highest voltage of 17.5 V. A condenser is expected to charge the battery due to the low voltage. The creator also mentioned that amid high recurrence street stimulation, the ride and comfort execution cannot be guaranteed.

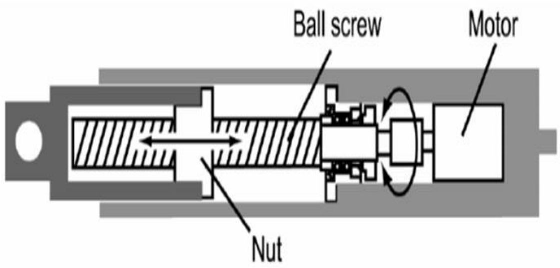

Fig-7. Indirect regenerative shock absorber of the ball screw type

Fluid Motion Rectifier

Instead of precisely converting direct motion to rotational motion, hydraulic/pneumatic systems were given in a variety of energy collector layouts for smoother activity and reduced mechanical friction energy distribution. The smoother activity and motion rectification can be imparted at the same time in the hydraulic framework, similar to other indirect drive regenerative shock absorber systems where the stroke speed is exactly increased. Tooth, Guo, for example, developed an efficiently controlled hydraulic suspension system by using an oil pump to provide hydraulic pushing factor in the shock absorbers, as shown in **Fig-8.**

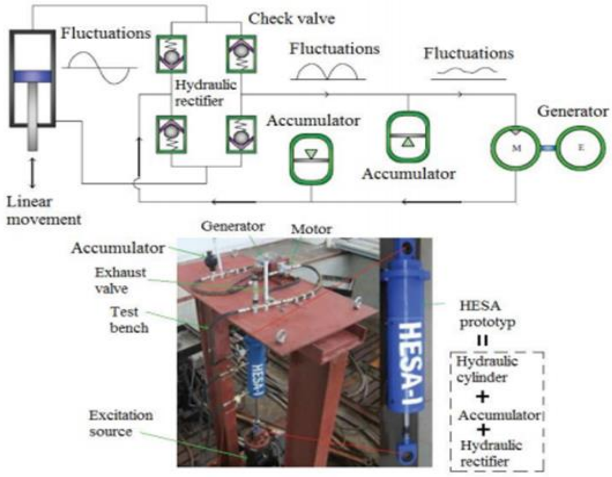

Fig-8. The hydraulic shock absorber prototype

The framework included single-direction check valves to control the flow of liquid, accelerometers in each of the four corners, and actuators and gatherers to reduce reaction time and ensure that a sufficient pressing factor is maintained in the framework. Wang and Gu suggested a similar hydraulic framework for stream amendment with four check valves and discovered that the gatherers may be improved to increase force productivity by up to 40%.[2]

In **Table-3**, various indirect drive regenerative shock absorber systems are summarized.

Table-3. Summary of the indirect drive regenerative shock absorbers

Presenter	**Mechanism**	**Voltage Output (V)**	**Power Output (W)**	**Vehicle (km/h) or Excitation Frequency (Hz) E**	**Energy Harvesting Efficiency**
Choi, Seong	Rack and pinion	15 V	40 W	20 mm at 3 Hz	N/A

Liu, Xu	Ball screw with two one-way clutches	N/A	24.7 W	2 mm at 4 Hz	51.9%
Kawamoto, Suda	Ball screw	N/A	44 W	80 km/h on class C road	N/A
Zhang, Zhang	DC generator connected to the hydraulic actuator	N/A	33.4 W	50 mm at 1.67 Hz	N/A

Hybrid systems and technologies

Aside from the direct drive and indirect drive frameworks, a number of improvements have been proposed to combine the various drive modes for improved dependability and damping execution. As seen in **Fig. 9**. Singh and Satpute presented a two-cylinder system in which the first cylinder acts as a shock absorber, channelling vibration through the vehicle suspension while also providing power to the secondary cylinder for increased speed. When the secondary cylinder burns out, the primary cylinder continues to function as a passive damper. A large amount of energy can be produced without sacrificing riding comfort or street-controlling performance.

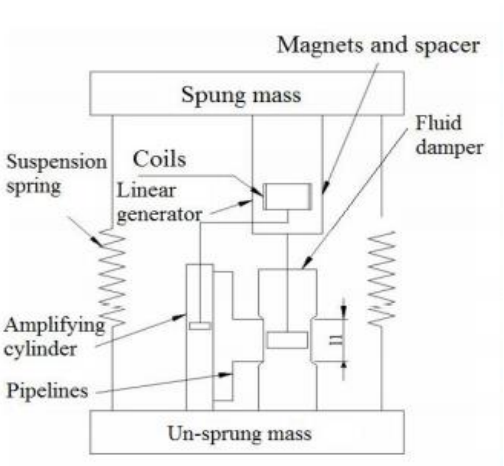

Fig-9. Hybrid dual cylinder regenerative suspension system

Despite the fact that the majority of hybrid systems feature a safeguard mode, the main disadvantage of hybrid systems is their low dependability, which is caused by the plan's complexity, which might potentially increase the risk of disappointment. When comparing the direct drive and indirect drive frameworks, a large number of segments can scatter an extra measure of energy, resulting in a poorer power yield. Furthermore, the shock absorber's space requirements make the hybrid structure less feasible.[2]

2.4 Faraday's law of induction

Faraday's law of induction (also known as Faraday's law) is an electromagnetism law that predicts how a magnetic field would interact with an electric circuit to produce an electromotive force (EMF), a process known as electromagnetic induction. It is the fundamental operating principle of transformers, inductors, various types of solenoids, generators, and electric motors. Faraday's law states that there is EMF on the conductive loop when the magnetic flux through the surface encased by the loop varies suitably, while the Maxwell–Faraday equation displays how a spatially shifting electric field consistently goes with a time-varying magnetic field. Faraday's law had been discovered, and one of its components (transformer EMF) was later characterized as the Maxwell–Faraday condition. The Maxwell–Faraday equation and the Lorentz force can be used to determine Faraday's law's equation.[7]

What is electromagnetic induction?

The cycle by which a current can be started to flow because of a changing magnetic field is known as electromagnetic induction. Electromagnetic induction is depicted by two basic laws:

This connects the magnitude of the electromotive force created in a loop to the rate of change of magnetic flux through that loop. The connection is strong.

$$\varepsilon = \frac{d\phi}{dt}$$

The potential difference across the unloaded loop is referred to as electromotive power, or EMF. Because both voltage and EMF are calculated using the same unit, the volt, it is common to think of EMF as voltage.

The application of energy preservation to electromagnetic induction results in Lenz's law. Heinrich Lenz first introduced it in 1833. Faraday's law tells us the magnitude of the delivered EMF, while Lenz's law tells us which way the current will flow. It states that the orientation is always with the intention of opposing the flux shift that caused it. As a result, any magnetic field produced by an induced current will be in the opposite direction as the original field change. With a minus sign, Lenz's law is typically fused into Faraday's law, allowing a comparable facilitate structure to be used for both the flux and the

EMF. In some circumstances, the result is referred to as the Faraday-Lenz law.

$$\varepsilon = -\frac{d\phi}{dt}$$

By and large, we control magnetic induction in a variety of wire loops, each of which contributes a similar EMF. As a result, an additional term N addressing the number of turns is usually used, i.e.

$$\varepsilon = -N\frac{d\phi}{dt}$$

2.5 Future direction for regenerative shock absorbers

The regenerative shock absorber's practicality has improved due to rapid breakthroughs in new technology. A regenerative shock absorber must meet the requirements for force yield, energy harvesting proficiency, and vehicle dynamic control in order to be installed on a vehicle. Flow regenerative shock absorbers have a number of flaws that several designers have attempted to remedy physically and electrically. Each step ahead in the exploratory area would bring them closer to the execution reality and their ability to sustain it. The constraint of bundling space is a disadvantage of direct drive regenerative shock absorbers. Because the coil speed of the magnets cannot be increased, the magnets, as well as the coils, must be sufficiently large to provide consistent large electromechanical coupling. The primary limitation of the indirect drive regeneration shock absorber is that the motion change component's complexity might influence the vehicle parts, resulting in helplessness or inconvenience. As a result, it is suggested that the regenerative shock absorbers future design incorporate more capable magnets, the coil arrangement is ideally outside the magnets, and damping is introduced in both the pressure stage and the recoil period of the shock absorber motion. To reduce the contact energy misfortune, it is also expected that the component be less muddled. The reaction time for a regenerative shock absorber with a hydraulic/pneumatic structure should be reduced in order to gain vehicle moment control.

Numerous investigates have been accomplished zeroing in on enhancing the efficiency of the regenerative shock absorbers, nonetheless, the integration with the automobile has not been paid to sufficiently yet. In future research, it is suggested that a unique model of the entire vehicle be considered as the stage for regenerative shock absorbers, because the assessment based on the entire vehicle suspension structure is more precise and accurate. A nonlinear suspension can also be read for its benefits in broadening the energy gathering data transfer in light of the entire vehicle suspension framework model. Another area to investigate is dynamic control. Because of the logical mismatch between the energy harvesting and vehicle dynamic control exhibitions, a control calculation is expected to strike a balance between the two based on the status of the street surface and the needs of the driver. When the dynamic control becomes the requirement and the other way around, a force producing component can be used as an activation component. In an ideal scenario, the control framework would be able to recognise an equilibrium point. As a result, self-powering can be done mentally if the energy gained via the transducer's recovery mechanism is sufficient to control the activation mode. As a result, future research should concentrate on the dynamic control calculation.

3. EXPERIMENT

For the experiment conducted in this project is to design and analyse an efficient power generating suspension system which can either be incorporated in the suspension system or as an external attachment on existing telescopic suspension in an electric vehicle. In our project we have considered the suspension of bikes in order to conduct an easy study.
Methodology:
- Design
- Calculations
- 3D model
- Simulink model and simulation
- Result calculation
- Comparison study

the experiment started with an idea of creating a power generation system and studying various papers to understand how the research on this topic is going on the latest technology used in application of this system in future vehicles.
The design was first generated for a rack and pinion system of power generation. The necessary components were also designed comparing to an average size of suspension and how the device can be externally fit on to the existing suspension system. The basic design parameters were then decided according to the fit of the device along with a suspension system in a motorcycle and based on required dimensions for sufficient power generation. The basic design parameters were:
No of teeth on gear: 27
No of teeth on rack: 40
Length of rack: 500mm
Diameter of gear: 60mm
The next step of the experiment process was the putting the design into paper. A basic suspension system belonging to a normal motorcycle was considered.

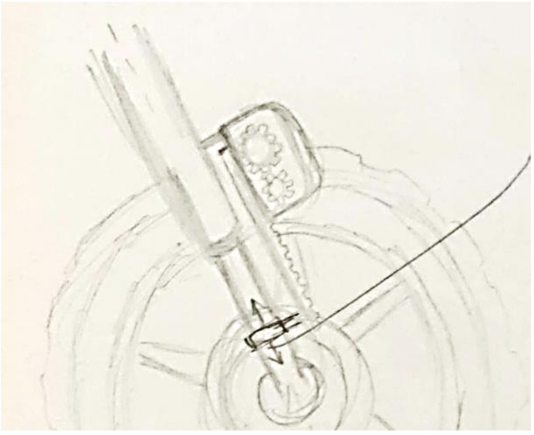

Fig - 10 Hand drawing of the system

The next step was to put the design into a 3d format. We used CATIA V5 to build the model.

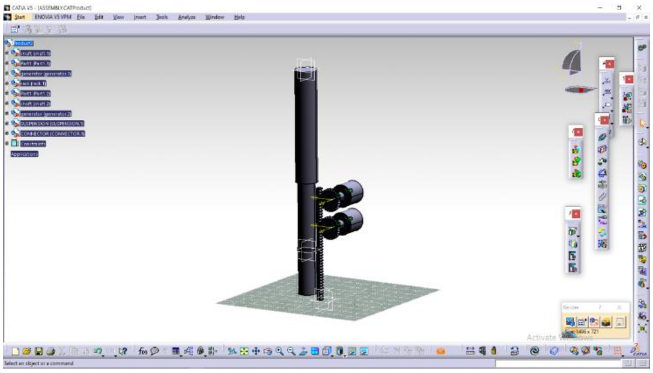

Fig – 11 3D model of rack and pinion system with generators

Fig - 12 3D model of rack and pinion system with generators

After designing the 3d model the design connections were considered from the rack and pinion to the generator and then to the diode and how the system produces power in order to charge the battery.

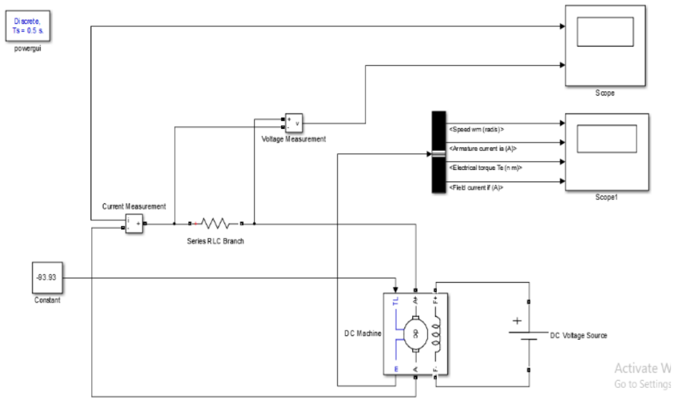

Fig - 13 Simulink model

3.1 Calculations and simulation.

Condition 1:
Consider a **RE classic 350 with rider**
Assume Maximum displacement of suspension = **15-20 cm** [average height of speed bump)
Weight of Motorcycle = **250 kg** (approx. with only rider)
Therefore, Force exerted by the bike on the ground = **250 x 9.81 = 2450 N approx.**

The rake angle is approximately **20 degrees.**
Therefore the force acting 20 degrees [rake angle of the bike] = **2450/(cos(20)) = 2607 N**
Equal and opposite force is acted on the suspension
Therefore, Torque on the gear = F x r = **2607 x 0.03**(r= radius of the gear taken to be 30mm)
Therefore, **T= 78.21 Nm**
In generator,
P(in)= T x w (where w is angular velocity) = P(mechanical)
P(out)= I x V (where I is current and V is voltage) = P(electrical)
Here considering 20cm displacement causing 20cm circumferential rotation out of total 188cm circumference, rpm= **6 (approx. = 0.6 rad/s)**
P(out)=P(in) x Efficiency [assuming 80% efficiency]
Therefore, **P(electrical) = 78.21 x 0.6 x 0.80 = 37.5 W**

Fig - 14 Simulink result graph

Condition 2:
Similarly for a **RE classic 350 with rider and passenger**
Total Weight of Motorcycle = **300 kg**
Following the similar steps in the case before,
Force exerted by the bike on the ground = **300 x 9.81 = 2943 N approx.**
The rake angle is approximately **20 degrees.**
Therefore the force acting 20 degrees [rake angle of the bike] = **2943/(cos(20)) = 3131 N**
Equal and opposite force is acted on the suspension
Therefore, Torque on the gear = **F x r = 3131 x 0.03**(r= radius of the gear taken to be 30mm)
Therefore, **T= 93.93 Nm**

In generator,
P(in)= T x w (where w is angular velocity) = P(mechanical)
P(out)= I x V (where I is current and V is voltage) = P(electrical)
Here considering 20cm displacement causing 20cm circumferential rotation out of total 188cm circumference,
rpm= 6 (approx. = 0.6 rad/s)
P(out)=P(in) x Efficiency [assuming 80% efficiency]
Therefore, **P(electrical) = 93.93 x 0.6 x 0.80 = 45 W**

Fig-15 Simulink result graph

Condition 3:
Consider a **BMW G310Rwith rider**
Assume Maximum displacement of suspension = **15-20 cm** [average height of speed bump)
Weight of Motorcycle = (**160+60)= 220 kg** (approx. with only rider)
Therefore, Force exerted by the bike on the ground = **220 x 9.81 = 2160 N approx.**
Rake angle = **25 degrees** approx.
Therefore the force acting 20 degrees [rake angle of the bike] = **2160/(cos(25)) = 2383 N**
Equal and opposite force is acted on the suspension
Therefore, Torque on the gear = **F x r = 2383 x 0.03**(r= radius of the gear taken to be 30mm)
Therefore, **T= 71.5 Nm**

In generator,
P(in)= T x w (where w is angular velocity) = P(mechanical)
P(out)= I x V (where I is current and V is voltage) = P(electrical)
Here considering 20cm displacement causing 20cm circumferential rotation out of total 188cm circumference,
rpm= 6 (approx. = 0.6 rad/s)
P(out)=P(in) x Efficiency [assuming 80% efficiency]
Therefore, **P(electrical) = 71.5 x 0.6 x 0.80 = 34.32 W**

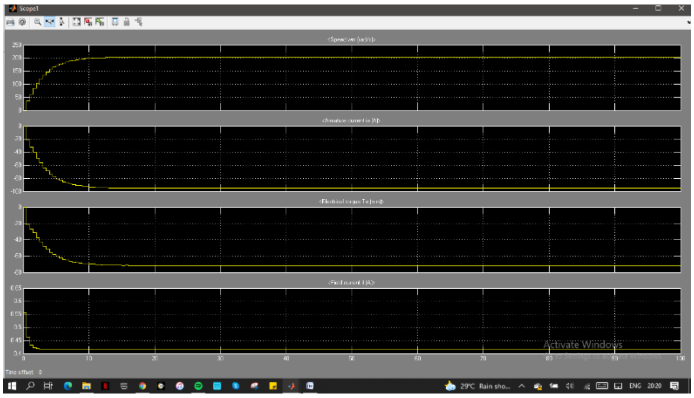

Fig-16 Simulink result graph

Condition 4:
Consider a **BMW G310Rwith rider and passenger**
Assume Maximum displacement of suspension = **15-20 cm** [average height of speed bump)
Weight of Motorcycle = (**160+60+60)= 280 kg** (approx. with only rider)
Therefore, Force exerted by the bike on the ground = **280 x 9.81 = 2747 N approx.**
Rake angle = **25 degrees** approx.
Therefore the force acting 20 degrees [rake angle of the bike] = **2747/(cos(25)) = 3031 N**
Equal and opposite force is acted on the suspension
Therefore, Torque on the gear = **F x r = 3031 x 0.03**(r= radius of the gear taken to be 30mm)
Therefore, **T= 91 Nm**
In generator,

P(in)= T x w (where w is angular velocity) = P(mechanical)
P(out)= I x V (where I is current and V is voltage) = P(electrical)
Here considering 20cm displacement causing 20cm circumferential rotation out of total 188cm circumference,
rpm= 6 (approx. = 0.6 rad/s)
P(out)=P(in) x Efficiency [assuming 80% efficiency]
Therefore, **P(electrical) = 91 x 0.6 x 0.80 = 43.68 W**

Fig-17 Simulink result graph

Condition 5:
Consider a **Harley-Davidson LiveWire with rider**
Assume Maximum displacement of suspension = **15-20 cm** [average height of speed bump)
Weight of Motorcycle = (**250+60)= 310 kg** (approx. with only rider)
Therefore, Force exerted by the bike on the ground = **310 x 9.81 = 3041 N approx.**
Rake angle = **24.5 degrees.**
Therefore the force acting 20 degrees [rake angle of the bike] = **3041/(cos(24.5)) = 3342 N**
Equal and opposite force is acted on the suspension
Therefore, Torque on the gear = **F x r = 3342 x 0.03**(r= radius of the gear taken to be 30mm)
Therefore, **T= 100.3 Nm**
In generator, **P(in)= T x w (where w is angular velocity) = P(mechanical)**
P(out)= I x V (where I is current and V is voltage) = P(electrical)
Here considering 20cm displacement causing 20cm circumferential rotation out of total 188cm circumference,
rpm= 6 (approx. = 0.6 rad/s)
P(out)=P(in) x Efficiency [assuming 80% efficiency]
Therefore, **P(electrical) = 100.3 x 0.6 x 0.80 = 48.1 W**

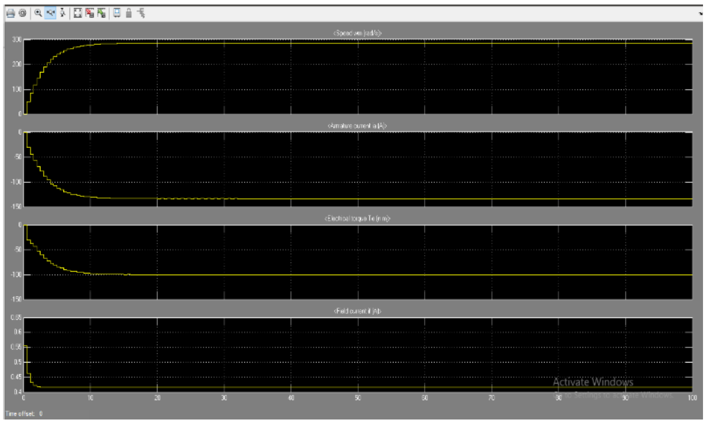

Fig 8.8 Simulink result graph

CONDITION 4.
Consider a **Harley-Davidson LiveWire with riderand passenger**
Assume Maximum displacement of suspension = **15-20 cm** [average height of speed bump)
Weight of Motorcycle = (**250+60+60)= 370 kg** (approx. with only rider)
Therefore, Force exerted by the bike on the ground = **370 x 9.81 = 3630 N approx.**
Rake angle = **24.5 degrees.**
Therefore the force acting 20 degrees [rake angle of the bike] = **3630/(cos(24.5)) = 4501N**
Equal and opposite force is acted on the suspension
Therefore, Torque on the gear = **F x r = 4501 x 0.03**(r= radius of the gear taken to be 30mm)
Therefore, **T= 135 Nm**
In generator,
P(in)= T x w (where w is angular velocity) = P(mechanical)
P(out)= I x V (where I is current and V is voltage) = P(electrical)
Here considering 20cm displacement causing 20cm circumferential rotation out of total 188cm circumference,
rpm= 6 (approx. = 0.6 rad/s)
P(out)=P(in) x Efficiency [assuming 80% efficiency]
Therefore, **P(electrical) = 135 x 0.6 x 0.80 = 64.8 W**

Fig 8.9 Simulink result graph

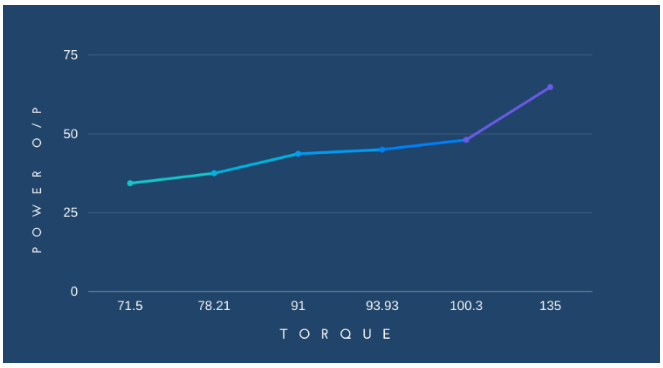

Fig 8.10 Graph of power output to the torque

After the calculations for rack and pinion method of power generating suspension, we considered a design, simulation and calculation for electromagnetic power generating suspension method. The parameters of design of this system were as follows.

The governing equation used in this model is faradays law equation

$$E = N\frac{\Delta\varphi}{\Delta t} \qquad \varphi = BA$$

Here the diameter of suspension considered is 80mm, and the coil is considered to be wind along the diameter od suspension upper fork which is 100mm diameter. Here,

Number of turns = **511**

Magnetic field B = **0.6 T** (magnet: rare-earth neodymium)

Area A = pi*(80mm^2) = **0.02 sqm**

E = 511 x (0.6 x 0.02)/1 = **6.132 V**

Wire standard is considered to be **20AWG copper**

Wire resistance = **5.346 ohms** (standard)

Total wire length = **511 x (circumference of upper fork)**

I = V/R = 6.132/5.346 = 1.1 A

P = I x V = 1.1 x 6.132 = 6.745 W

Also comparing with another method used for reference,

Diameter of coil (D) : 0.0254 m

Diameter of wire (d) : 0.25 mm = 0.0003 m

Magnetic field intensity (B) :1 T

Layers of winding (n) : 6

Length of winding (L) : 0.1148 m

Dimensions of magnet: 50 x 25 x 2.5 mm

the suspension system was modelled and based on known parameters the damping coefficient was determined. Then the model was modified to determine the output emf, current and opposing force.

The maximum bump force on the wheel = 1040 N Motion ratio = 0.6

Maximum force on the suspension = 1040/0.6 = 1733.33 N

When the coil advances past the magnets, an opposing force will begin to originate. The opposing force is calculated and reduced from the bump force to get the actual force acting on the system. The total unsprung mass here is 60 Kg. Mass considered for 1 wheel is 15 Kg. The suspension travel from mean position is given by x. The corresponding acceleration and velocity are represented by a and v. ma = F – kx – Cv k represents suspension stiffness. C represents damping coefficient. k = 25 N/mm

C = 0.2 Ns/mm

a = 1/m * (F – kx – Cv)

v = ∫1/m * (F – kx – Cv) dx

x = ∬1/m ∗ (F – kx – Cv) dx

The emf induced is,

emf = dϕ/dt

ϕ = NB.A cosθ

dϕ/dt = NB cosθ x dA/dt

dA/dt = D x dx/dt = Dv

∴ emf, e = NBDvcosθ = n x (L/d) x BDv cosθ

In order to account for the cosθ factor and to account for efficiency the emf obtained is multiplied by a factor of 0.5. The external resistance is represented by R. The current induced, i = e/R The system will generate an opposing force. This is generated due to the coils present in the region of magnetic field. The opposing force, F* = i x B x (z/d) x ΠD sinθ is reduced from the bump force and given as input to the system.

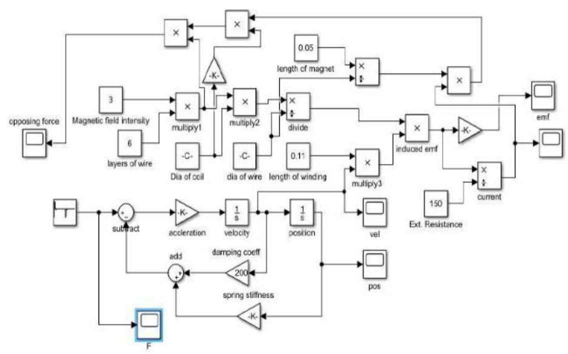

Fig 8.11 Simulink model of electromagnetic suspension regenerative suspension

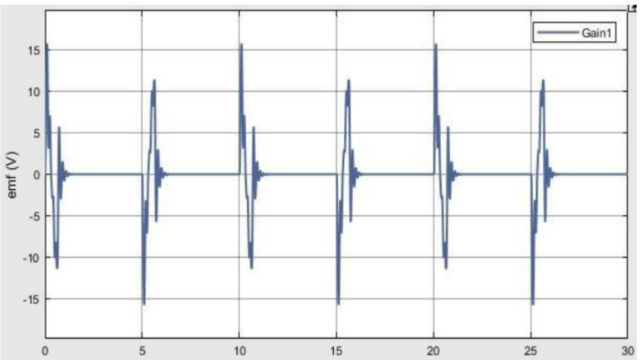

Fig 8.12 Simulink result graph

The emf plot shows an instantaneous surge in the voltage initially which can't be used as it occurs for a very short period of time. It occurs due to a very high instantaneous force.

4. CONCLUSIONS

Heat energy is squandered as a result of the vibration energy of the vehicle suspension system. By employing a regenerative system, lost energy is converted into useful energy, such as electrical energy, and fuel consumption is minimized. Electromagnetic suspension is the most popular type of regenerative suspension. Electrical energy is generated by using a regenerative system. When a vehicle travels down a rough street, the alternator produces more energy. The alternator is attached to the battery, which charges it.

The energy recovery efficiency, recovery mechanism, and parameters that affect the energy-regenerative suspension system's regenerative and damping properties are investigated. The regenerative suspension system can achieve roughly 50 percent energy efficiency. Automobiles, off-road vehicles, and passenger cars, for example, can recover 105 W, 380 W, and 1150 W of energy at 60 km/h on a typical road pavement. Fuel consumption per 100 km is decreased by around 0.4 L on bad roads, by about 0.07 L on good roads, and by about 0.2 L on average roads.

The main conclusion from the project is that after the study comparing the virtual assessment of both types, which is, electromagnetic and mechanical method of power generation from suspension, it is found that the mechanical system produces higher amount of power in a unit time with an average of **35W**. Whereas, the electromagnetic system produces low amount of power with an average of **6W** in a given unit time. But the losses in the mechanical power generation system is comparatively higher and the maintenance is also a lot higher. But the chances of losses in electromagnetic power generating suspension is comparatively lesser and does not cause friction and noise.

REFERENCES

[1] Power Generation by Using Suspension System Himanshu S. Rewatkar, Vicky R. Gedekar, Kunal L. Parate, November 2017

[2] A Comprehensive Review of the Techniques on Regenerative Shock Absorber Systems, Ran Zhang, Xu Wang and Sabu John, May 2018

[3] Review of Methods for Energy Harvesting from a Vehicle Suspension System, Jesper Eriksson Shwana and Piroti, KTH Royal Institute Of Technology School Of Engineering Sciences, 2016

[4] Research Review of a Vehicle Energy-Regenerative Suspension System, Xueying Lv, Yanju Ji, Huanyu Zhao, Jiabao Zhang, Guanyu Zhang & Liu Zhang, January 2020

[5] Regenerative Suspension System, Prof.P.B.Magade, Manoj Narute, Suraj Kinhale, Mahesh Kutwal, Yogesh Marakad ,Dept. of Mechanical Engineering, Zeal College of Engineering and Research Narhe, Pune, Maharashtra, India, April 2018

[6] Speed Bump Generating Electrical Power Capstone Design – EGR 4402, Ahlam Laksimi, Al Akhawayn University, February 2019

BIOGRAPHIES

Prof. Smitha B.S
Automobile dept, NHCE Bangalore, Karnataka - India

Hibel Hussain
Final year student, BE Automobile
NHCE Bangalore, Karnataka - India

Johnjo Josmon
Final year student, BE Automobile
NHCE Bangalore, Karnataka - India

Muhammed Nihal K.C
Final year student, BE Automobile
NHCE Bangalore, Karnataka - India

Rohith V
Final year student, BE Automobile
NHCE Bangalore, Karnataka - India