Rig Design and Experimental Energy Harvesting from Automotive Suspension System Using Mechanics and Hydraulics

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Acknowledgement

I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this work at every step and for every new thought which You setup in my mind to improve it. Indeed I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

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Abstract

From the day first of invention of fuel engines, its lower efficiency and environmental concerns were always problematic. Only 30-40% of total heat energy of fuels is used in engines for mechanical work and rest of all is lost. Vibrational energy of shocks can be converted to electrical energy by means of some mechanical setup. This setup will consist of a to-and-fro motion to rotary motion convertor. An alternator will be deployed that will be powered by this rotary motion caused by suspension system and it will ultimately power the battery or the accessories directly. Aim of the project was to design a testing rig so that the variable data of vibrational amplitude can be applied to the shock absorber along with the power harvesting mechanism for experimental analysis. To test all that setup a testing rig was be designed that will be equipped with shock absorber, a motion converting mechanism, an alternator and a pneumatic actuator that will be a tool for applying real time obtained data. It was not possible to apply variable data with the cam follower mechanism, so a pneumatic cylinder is used along with power supply. To apply data acquired automatically, Arduino is used along with MOSFET and SD card module. Energy harvested was calculated and the effect on the stiffness of shock absorber after adding power harvesting mechanism is also analyzed.

Keywords: Rig Design, Power Harvesting, Data Application, Suspension system

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1. Introduction

From the day first of invention of fuel engines, its lower efficiency and environmental concerns were always problematic. Mainly we will be focusing on the automobile engines in this regard. Automobile is one of the most important and biggest industry of today's time. Only 30-40% of total heat energy of fuels is used in engines for mechanical work and rest of all is lost through friction or residual gases. Lower efficiency means more fuels to be burnt and more fuels mean more carbon emissions to the atmosphere. That is a double disadvantage for the engine manufacturers. Fuel reserves are falling day by day which is more concerning for upcoming years for this industry. Scientists and researchers are working hard to overcome this problem from day one either on individual or industry level. Main concern is that these energy resourced fuels are going to end one day and all the world's industry will suffer the consequences. So it is time that we focus on possible energy regenerations from with-in the vehicle system or from other renewable energy methods. There are two options available for the think tanks, either to make more efficient engines or to rely on some renewable energy. We will go with-in the system energy regeneration possibilities and in this project we will discuss the possibility of regenerating the heat energy that is lost due to the suspension system of a vehicle. The concept of electric or hybrid vehicles was presented only because of fuel shortages and the environmental concerns related to the burning of fuels. Regenerative braking system (RBS) has already been developed and now this project is about giving a proof of concept about regenerative suspension system. Real time data will be obtained from a vehicle's suspension system while traveling on different kind of terrains. A testing rig will be designed where this obtained data will be applied to suspension of vehicle along with a regenerative suspension system mechanism and the energy harvested will be calculated. Effects on suspension system's working will also be discussed after the addition of energy harvesting mechanism.

1.1. Problem Statement:

In automobiles, where many other sort of energies are unused or lost, suspension system also dissipates energy in the form of heat as well. Regenerative braking system has already been developed and is in use so there is a need to develop a system that recovers the energy dissipated in suspension system as well. IC engine has to move the vehicle and other than that many accessories (power windows, steering system, air conditioning etc.) are also powered by alternator which ultimately uses brake power of the engine and reduces efficiency of system. Energy harvested from suspension system can be used to power these accessories. Prime purpose is to reduce the load on engine and increase its efficiency while using alternative power available on the other ends that were being lost otherwise. The capability of this recoverable energy varies directly with the weight and size of vehicle. A prototype is needed to check the fact that whether this mechanism is capable of regenerating energy or not.

1.2. Research Idea & Concept:

Vibrational energy of shocks can be converted to electrical energy by means of some mechanical setup. This setup will consist of a to-and-fro motion to rotary motion convertor. An alternator will be deployed that will be powered by this rotary motion caused by suspension system and it will ultimately power the battery or the accessories directly. To test all of that setup a testing rig will be designed that will be equipped with shock absorber, a motion converting mechanism, an alternator and a pneumatic actuator that will be a tool for applying real time obtained data. The concept is to design a prototype that will show that how energy harvesting is possible from suspension system and what effects it will have on the vehicle comfort after deploying energy harvesting mechanism. In the start we are looking forward to perform this test on a motorbike and then it can be carried out on a larger scale for a car or truck.

1.3. Aims & Objectives:

- Rig design for the testing of an Energy harvesting mechanism of an automobile suspension system.
- Data acquisition from the suspension system on different sort of roads.
- Applying this acquired data on a shock absorber with the help of a pneumatic actuator along with energy harvesting mechanism.
- Calculating the power harvested.
- Studying the effects on the vehicle suspension system (vehicle comfort, suspension life span).

2. Literature Review

People have been working on enhancing the performance of fuel engines from the day they invented. Renewable energy is also under consideration from almost 2,3 decades. In automobiles regeneration is possible from braking system and suspension system. Regenerative braking system is already deployed but regenerative suspension is still in research process. People have been working on different methods for energy harvesting from suspension system. The systems that were used before includes piezoelectric effect, magnetic coils for shock absorber and active suspension systems. Most of the research is still limited to simulations based and practical experiments were never done on that mechanism.

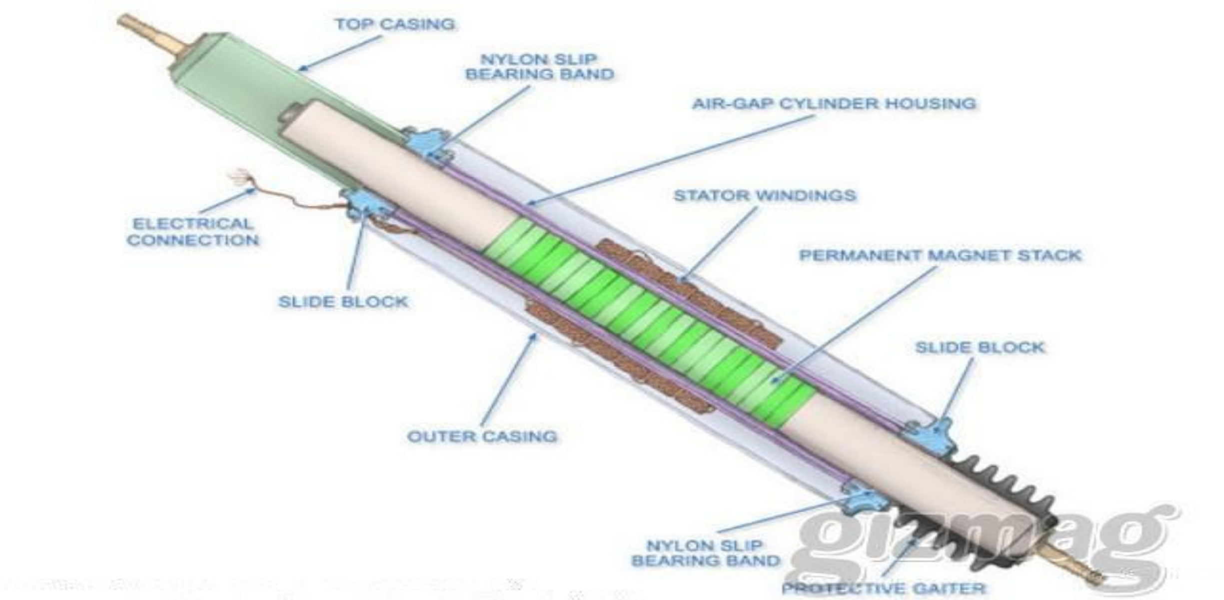

FIGURE 1. HARVESTER BASED SHOCK ABSORBER WITH LINEAR ELECTROMAGNETS

At start electromagnetic shock absorber were introduced and validated by different researchers. Harvestable energy was between 45 to 7000 watts for different operating conditions and different vehicles. But this was not verified experimentally, and research was only literature and calculation based.

2.1. Electromagnetic Flux Induction Within the Shock Absorber:

Different types of shock absorbers have been proposed in the past for regenerative purposes. Worthy result for energy harvesting. The accumulator is used in mechanical regenerative suspension systems that convert the kinetic energy of spring into potential energy but it is a very spacious set up and has a high weight which is not suitable Some of them will be discussed here that are more feasible to apply commercially and have an in case of automobiles. So electromagnetic regenerative suspension systems can convert the energy stored in springs into electric energy and are less space occupying and easy to install with an advantage of high performance. Four types of electromagnetic suspensions are under research. Technologies are many but their execution into vehicles is the real issue. The main purpose is to use existing information about different concepts of regenerative suspensions and make a modern and efficient system, which is simple enough to harvest energy without complexities. It was required to conduct an experiment, keeping the aspect of simplicity in mind, a suspension system that should consist same components as a normal suspension, through which energy harvesting is possible with the help of copper coils and magnets. The theory of electromagnetic induction conveys that when a conductor is placed between a changing magnetic field, causes the voltage to produce across the conductor. This process causes an electrical current to be induced in a conductor. In the suspension system, the wheel is vibrated, and it causes the spring actuation and this actuation is linear. The current-carrying conductor shaft will be attached to the suspension head in the magnetic suspension system. The spring actuation moves the coil linearly along the suspension. When the current-carrying conductor is moving linearly the magnets installed inside the suspension cavity, cuts the magnetic field of system, resulting in the induction of electromagnetic induction force in the conductor. all this process is obeyed by Faraday's law of induction.

FIGURE 2. ELECTROMAGNETIC FLUX INDUCTION WITHIN THE SHOCK ABSORBER:

This method is in which coiled magnets are used within the shock absorber. The magnetic flux of the magnet is a deciding factor of electricity induced in the coil, ring magnets have the highest flux density, and they are concentrated at the center. There are many types of ring magnets available, the major ones being Neodymium and Ferrite magnets. Neodymium magnets have a higher magnetic flux density than ferrite magnets. Ferrite magnets were chosen because Neodymium are expensive, and they were out of budget. The magnetic field of one ring magnet would not be sufficient so in order to increase the magnetic field intensity, five ring magnets of the same size are used combined. Spring actuation will be around 80-100mm for energy regeneration and using a spring of free length of 170-200 will be advantageous which is more than the expected actuation. The spring will compress about half of its free length and buckling, and failure will be avoided. It is convenient to use a less thick and less stiff spring and wire thickness so that it actuates with a small amount of load. A spring of high index will be helpful in this regard. Springs and magnet sizes will determine the size of the body of the suspension. For circular magnets and springs, a cylindrical shape was chosen which also facilitates the actuation process. Aluminum was used due to its non-magnetic nature, lighter weight, and good strength. The cylindrical body will be kept immobile because of magnets placed inside and a spring is installed outside of the body.

Potential drop occurring is measured in the current-carrying conductor by joining the ends of copper wires with the multimeter adapter pins. The damper is not included in this prototype which restricts the scope of use in industry. Damper addition will complete the suspension system and energy dissipated from the damper will be added to the total electricity developed in this process.

FIGURE 3. DIGITAL MULTI-METER

Potential drop was measured with the help of a multimeter by joining its ends with wires that were carrying the current. The problem with this research was that the damping system was not taken in the consideration . without the damper the experiment was not valid practically, but it is proposed that if we add the damper system it will surely reduce the vibration amplitude but it will take us more close to the realistic values of parameters.

2.2. Energy Regenerative Shock Absorber (ERSA) with MTS Testing System:

This process consists of four components. Energy capture, motion convertor, generation, and storage of energy. In the first step vibration energy is captured by a component that consists of three cylinders, upper cylinder, middle cylinder, and lower cylinder. With the roughness of the road or speed fluctuations, linear reciprocating motion occurs between the upper and middle cylinders. Then a pair of helical gears are used for the conversion of linear reciprocating motion to rotary motion and this is called the conversion module. This rotary motion is fed to a generator shaft which is called a generation module. In the end, this generated energy is stored in a super capacitor which powers the auxiliaries.

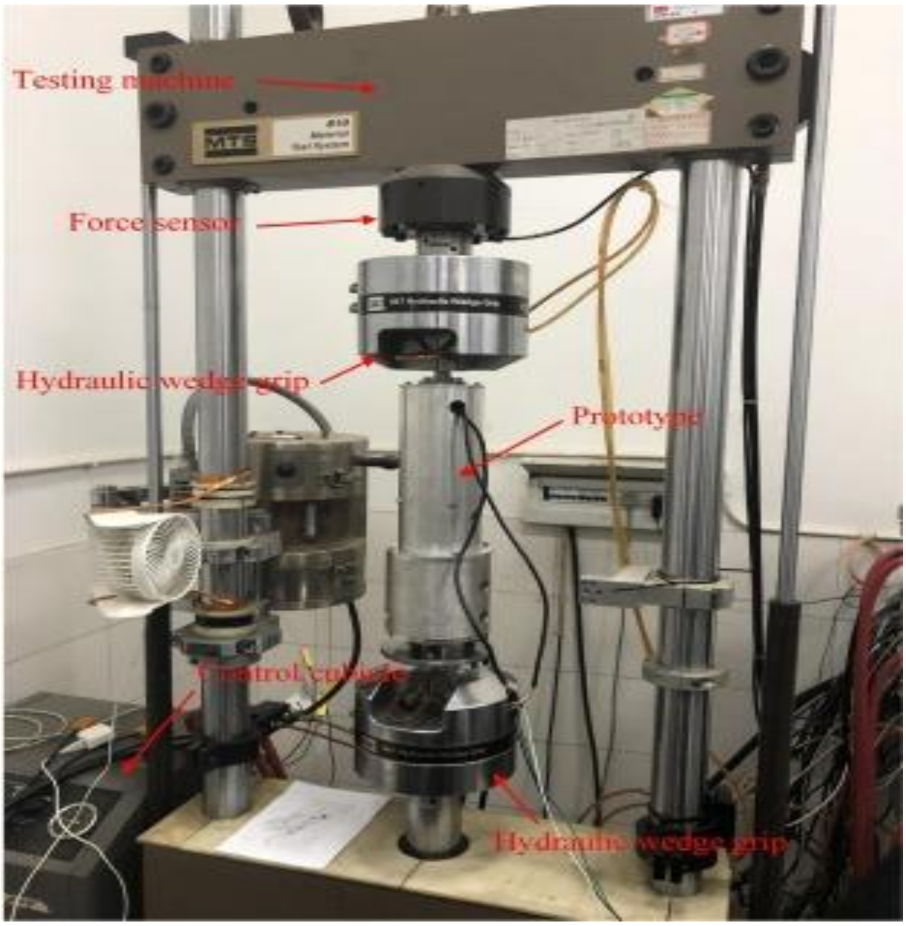

FIGURE 4. ENERGY REGENERATIVE SHOCK ABSORBER (ERSA) WITH MTS TESTING SYSTEM

The testing of this ERSA system was done on a servo-hydraulic mechanical testing and sensing system (MTS). The MTS system recorded the input force and displacement. The output electric force is displayed on a screen and recorded by a flash drive connected to that screen as well. Average amplitude of 5-10mm is recorded when the vehicle travels at 30km/h. frequency of amplitude ranges between 1-10 Hz. But due to the experimental constraints on equipment, the prototype was tested under sinusoidal waves excitation and varying amplitudes of 3-7 mm and frequencies of 1- 2.5 Hz.

This system was observed under different frequencies and amplitude ranges. A graph representing the regenerated energy according to different operating conditions shows that the peak energy recovered was around 50W.

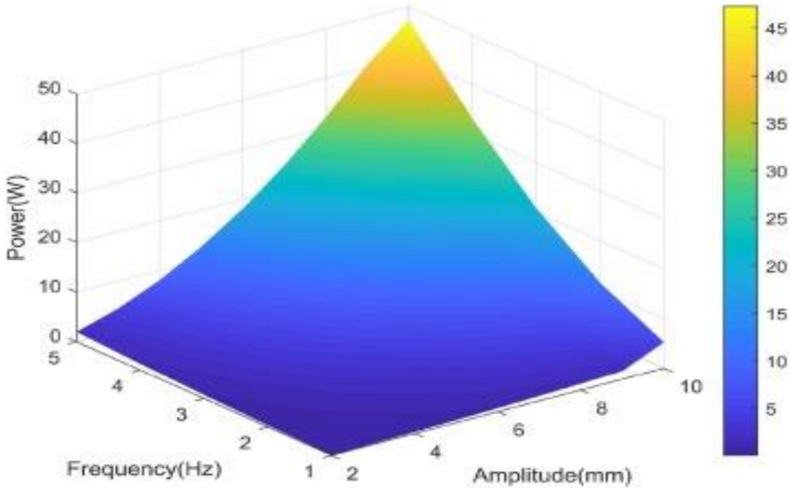

FIGURE 5. 3D GRAPH OF FREQUENCY, AMPLITUDE AND POWER

2.3. Barrel Cam Follower Shock Absorber:

RSA proposes a barrel cam follower mechanism because of the advantages over other motion conversion mechanisms. It is easy to manufacture because its parts are smaller and more compact than rack and pinion mechanism, algebraic screw linkage, and other mechanisms. Backlash is also eliminated in the cam follower mechanism compared to gears. RSA can harvest energy from the suspension system with the help of this follower cam mechanism to power low wattage equipment and can also store energy for later usage. Consisting of a vibration input module, transmission, generator, and power storage module. The transmission module is of prime importance and this proposed RSA converts the irregular reciprocating motion into the rotary motion of the generator shaft. The transmission module has bevel gears, input-output shafts, and a one-way bearing. A combination of bevel gears and one-way bearings is used for the transfer of motion from the input shaft to the unidirectional rotation of the generator. The follower moves in the helical groove to rotate the input shaft. In a downward stroke, the barrel cam rotates counterclockwise, and the one-way bearing directly engages the input and output shaft for transferring the motion to the generator shaft.

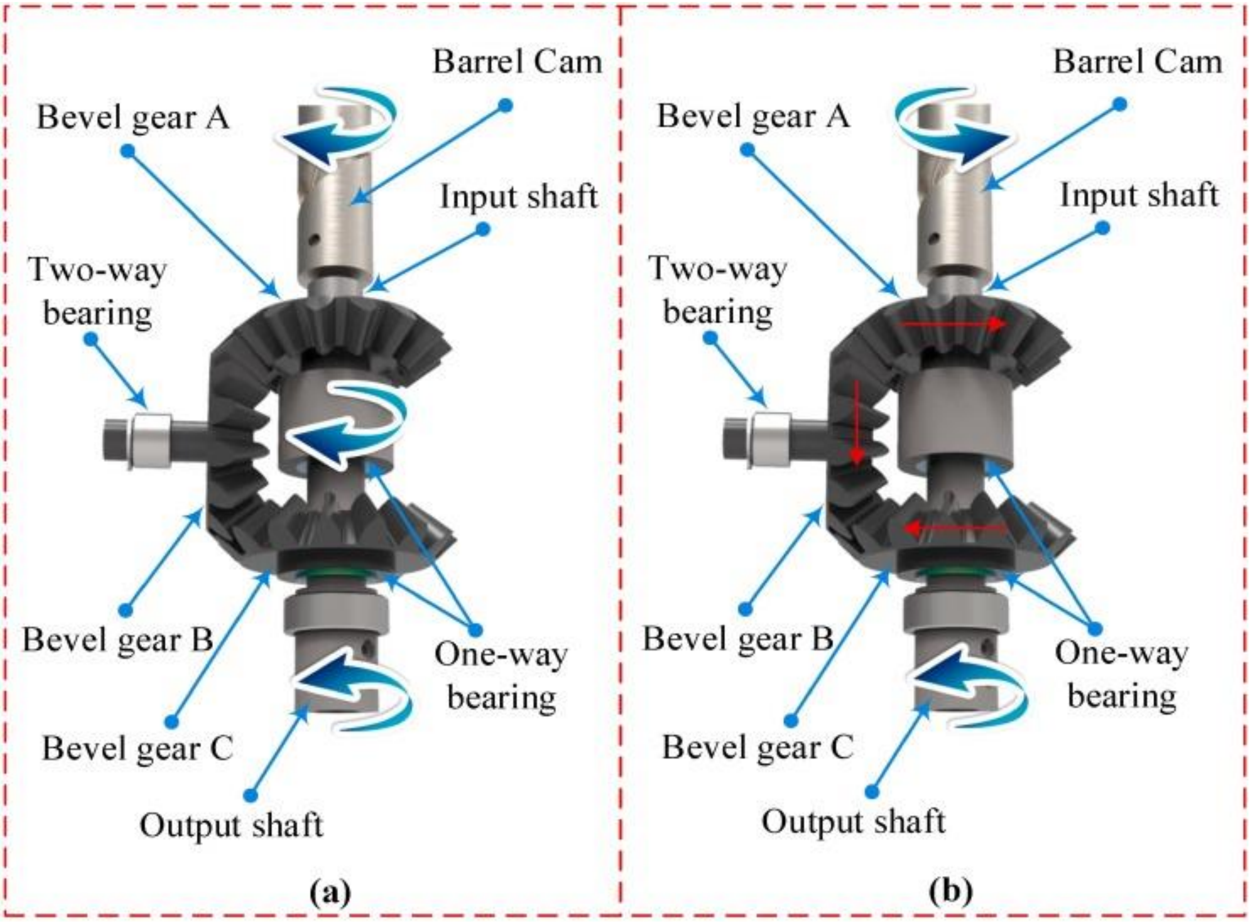

FIGURE 6. BARREL CAM FOLLOWER SHOCK ABSORBER

The experiment was done for the dynamic energy harvesting performance on an Axial/Torsional testing system along with MTS. The experiment was done with sinusoidal input with a mean square amplitude of 5-10mm with frequencies ranging from 1-3 Hz. These values are estimated for the vehicle traveling at 30km/h on a semi-rough road. The picture illustrates different steps of the testing from RSA’s installations, data analysis, and the generated power on the oscilloscope screen. The research gap that is obvious is that the applied data is simultaneously sinusoidal and constant amplitude with a regular frequency. This is not the case in real-life scenarios. However, it gives an appropriate overview of how the regenerative shock absorbers are capable of harvesting energy from the suspension system.

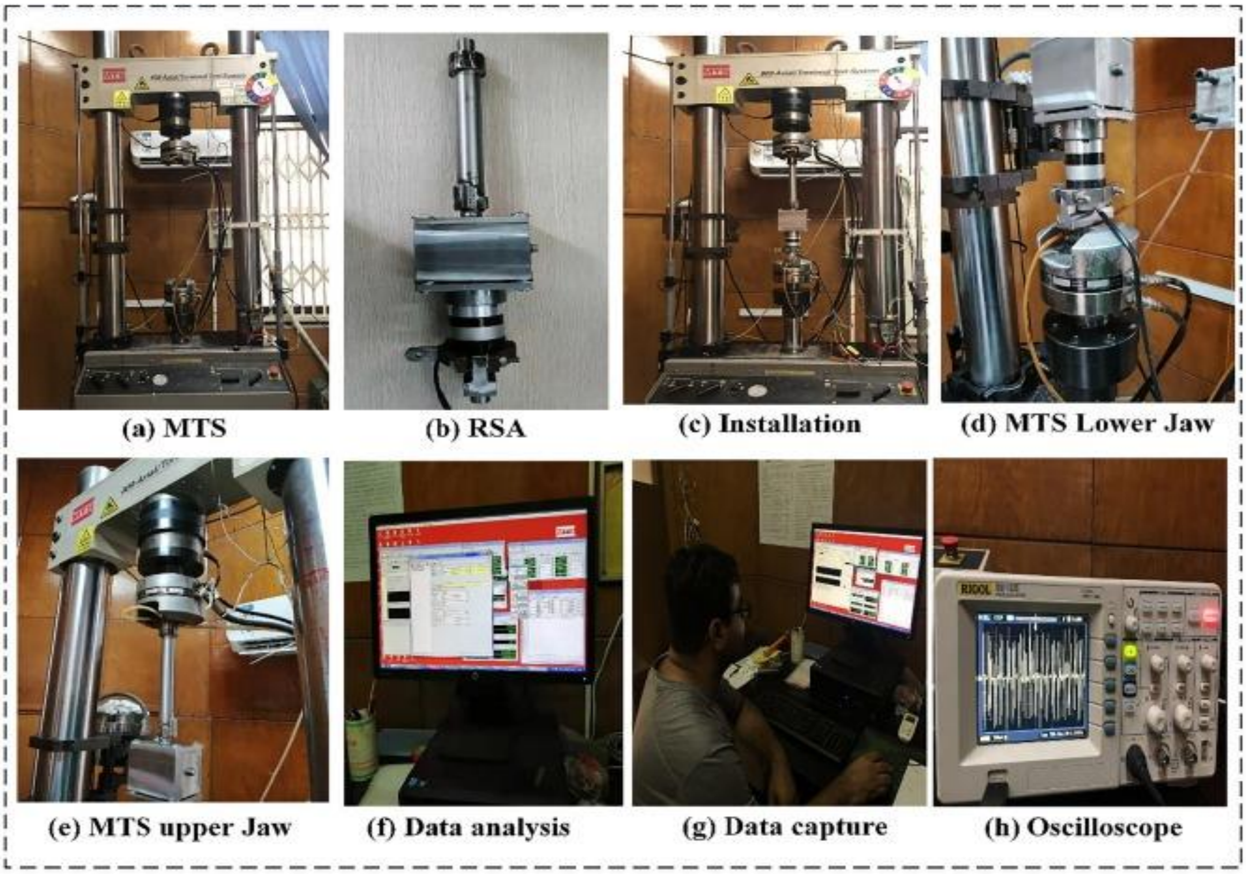

FIGURE 7. TESTING SYSTEM ALONG WITH MTS

2.4. Rotary Regenerative Shock Absorbers:

Rotary regenerative shock absorbers are not exactly the shock absorbers that we use conventionally. it is actually a controlled electric machine that provides a force that helps or counteracts the suspension linear motion. This machine can potentially convert the mechanical motion to electrical power. So the kinetic energy from the irregularities of the road can be used to generate electricity and power the auxiliaries of automobiles. Linear motion is converted into angular displacement with the help of a linkage. The angular speed is applied to the low-speed high-torque shaft of the gearbox, during damping. And this shaft of the gearbox is coupled to the rotor of an electric machine. And this electric machine acts as a generator as the work is being done on its shaft.

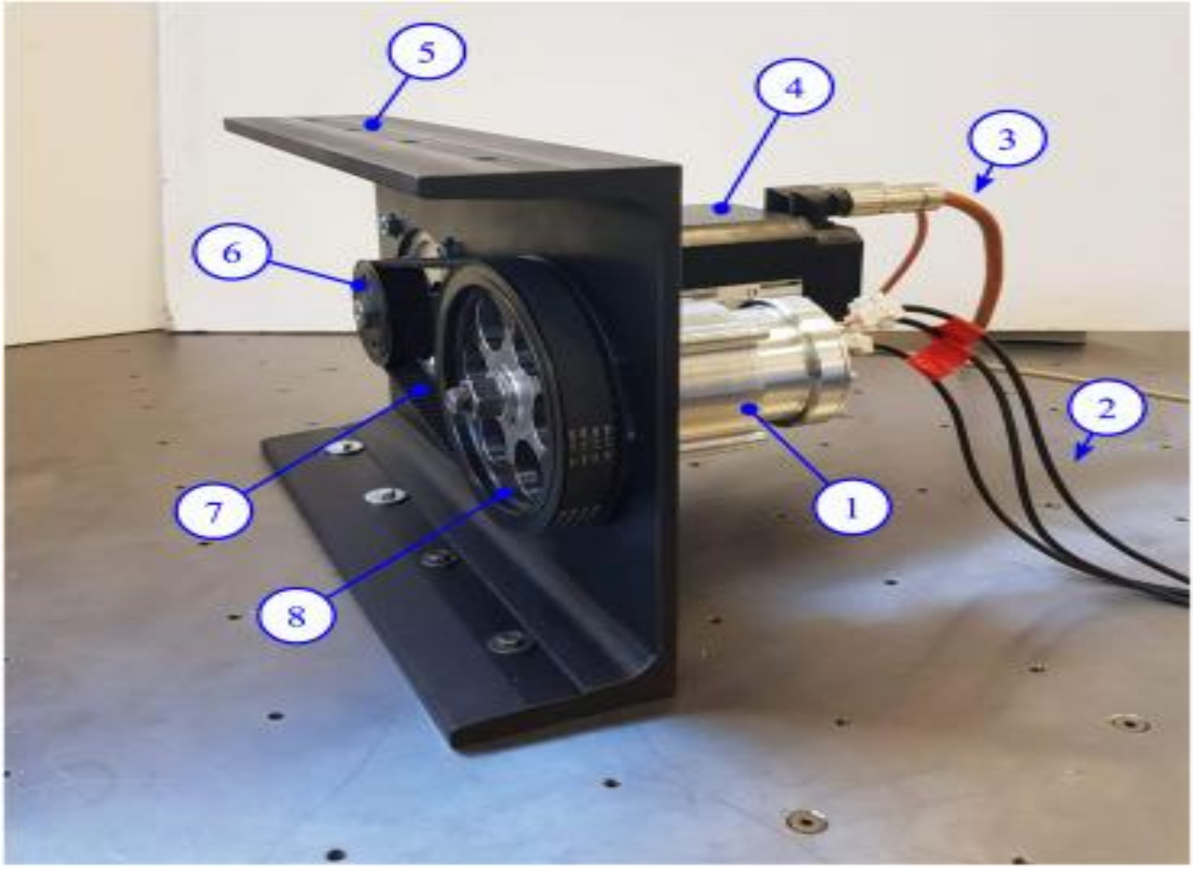

FIGURE 8. ROTARY REGENERATIVE DAMPER PROTOTYPE (1), PROTOTYPE PHASES (2), DRIVING MOTOR PHASES AND FEEDBACK (3), DRIVING MOTOR (4), TEST RIG FLANGE (5), DRIVING PULLEY (6), BELT (7), DRIVEN PULLEY (8).

3. Rig Design Methodology

In this project, the prime purpose was to design a rig where the shock absorber can be tested after equipping it with the power harvesting mechanism. This mechanism consists of a rack and pinion which will be connected with the shock, and it will be used as a linear motion to rotary motion conversion module. For that purpose, the rack will be attached to the reciprocating shock absorber, and it will rotate the pinion, which is connected to the generator shaft, and it will ultimately drive the generator shaft. The rig will be responsible for the mounting of the shock absorber and the rack pinion along with the generator

After all the mountings are done the main problem is how to apply the force on the shock absorber.

3.1. Methods for Variable Data Implementation:

1. A pneumatic actuator is a device that consists of a cylinder and piston usually double-acting. It operates on high-pressure air. Two ports on both sides of the piston are responsible for the to and fro movement of the piston. Its movement can be controlled by an electric circuit by giving the positions of the piston rod with respect to time. It is feasible for our testing because we have to apply varying amplitude and variable frequency data for the shock absorber testing.
2. Cam follower mechanism power by electric motor can also be used to reciprocate the shock absorber but the problem with this technique is that it will only have constant amplitude of reciprocation with a constant frequency at a time. While our data consists of variable amplitude and frequency.

FIGURE 9. PNEUMATIC CYLINDER

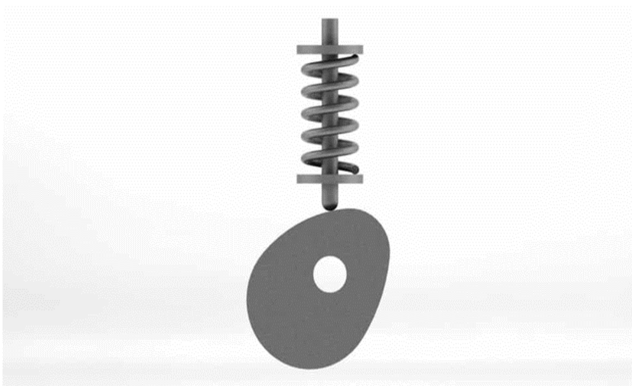

FIGURE 10. CAM FOLLOWER MECHANISM

After comparing our requirements and the specifications of both of the methods I have used the pneumatic actuator to make sure that the data we acquired should be properly implemented to the suspension system.

3.2. Testing Rig Assembly:

For that purpose, a pneumatic actuator will be used that will be mounted on the top of the upper plate of the rig. The rig will be consisting of three plates upper plate, center plate, and lower plate. The lower plate will be on the ground and the shock absorber will be connected to it on its lower side. The upper plate will be the holding for the force applying mechanism. And the center plate will be the joining part between the shock absorber and the pneumatic actuator. The rack will also be connected to the center plate.

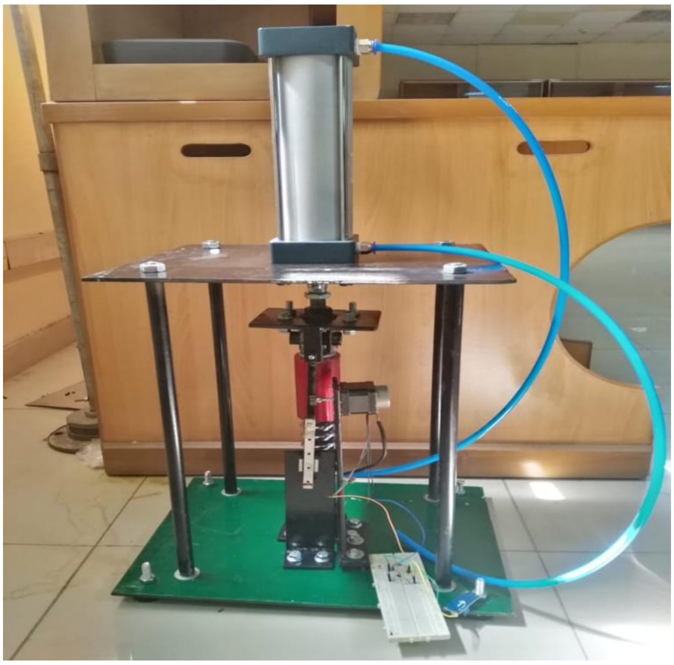

FIGURE 11. TESTING RIG

The Upper and lower plates are stationary while the center plate will be a floating one. All the amplitude provided by the pneumatic actuator will be transferred to the center plate that will ultimately press the shock absorber. For the free movement of the rack, a slider bearing is also used, and the rack will be mounted on the top of that. This is to overcome the losses due to friction.

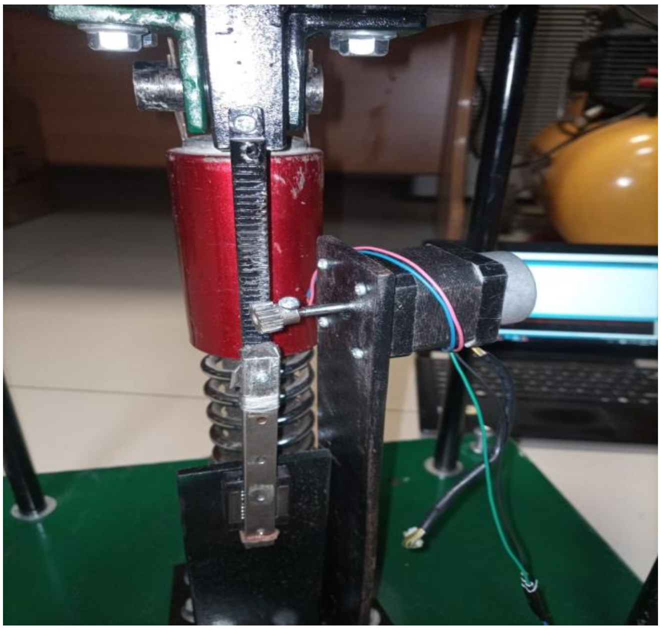

FIGURE 12. RACK & PINION INSTALLED IN TESTING RIG

All the material used for the rig design is mild steel because it has to withstand considerable forces applied by the pneumatic actuator. The data that will be applied to the actuator was already obtained by a real-life shock absorber of a motorbike on different road surfaces and at different speeds.

There are three mountings on the lower plate. One is L plates for the holding of the shock absorber’s lower end. Another L plate is connected to the lower plate that holds the slide bearing and the rack. On the third L plate, the generator will be mounted.

Center plate from the bottom side will be connected to the upper end of the shock absorber and from the top side it will be connected with the arm of the pneumatic actuator. The rack will also be connected to the center plate and the plate will be responsible for the movement of rack along with the pressing of the shock absorber.

The upper plate will hold the pneumatic actuator. The actuator will be connected to the plate with the help of four bolts that go through the actuator’s body. The actuator’s arm will also pass through the upper plate from a hole of 50mm.

The parameters that were of interest while designing the test rig were, the applied force, the mountings and the vibration control.

4. Data Implementation

The purpose was to give a proof of concept that energy can be harvested for the vibratory motion of suspension system. In order to minimize the margin of error real life data of the motion of shock absorber was obtained with the help of some sensors and that data was amplitude vs time. Now that data was to be applied to the shock absorber as it is.

The components that were required or data implementation was as follows.

1. Pneumatic Cylinder
2. Solenoid valve
3. SD card module
4. MOSFET module
5. Arduino mega
6. Power supply

The pneumatic cylinder was controlled by a solenoid valve which regulates the pressure in the cylinder chamber or in other words it controls the position of pneumatic cylinder arm. A compressor of 50ltr was used for compressing the air at 8 bar. Compressed air was fed to the solenoid valve. Solenoid valve can be controlled with Arduino. In Arduino the data was coming from a SD card module. All the data acquired at first place was stored in SD card that was the feeding mechanism for the Arduino.

4.1. Solenoid Valve:

Solenoid valve is a 5-valve system that controls the in and out flow of compressed air and the direction of movement of pneumatic cylinder. Its working frequency is 4Hz while our requirement for the frequency is 3Hz. We required solenoid valve because it is capable of variable frequencies and amplitude. It requires a 24 volt dc power supply for its functioning.

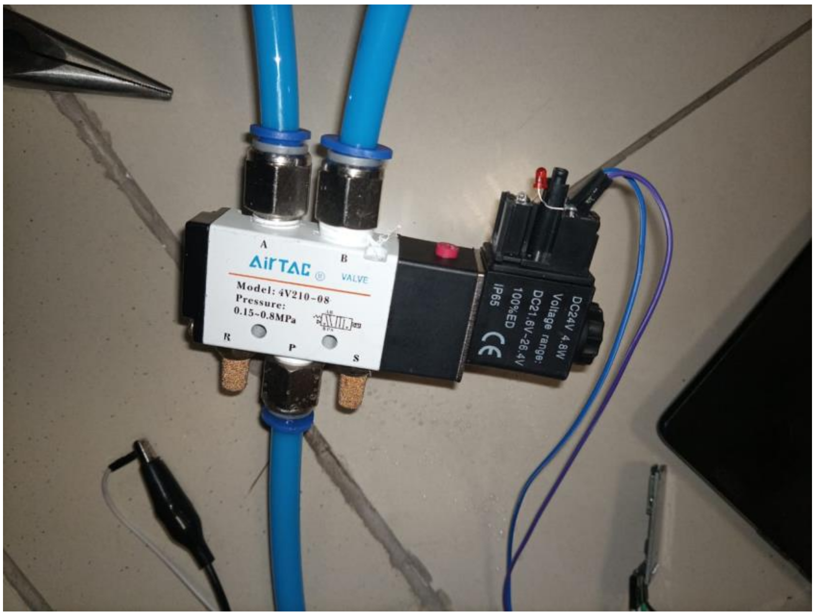

FIGURE 13. SOLENOID VALVE

4.2. Power Supply:

Power supply is used to provide dc voltage up to 30 volts. We required it for the solenoid valve as it requires 24-volt dc for operating.

FIGURE 14. POWER SUPPLY

4.3. MOSFET Module:

It is required for the control of variable voltage. As of our system we also required variable voltage for the different operating conditions. It was connected with Arduino form where it was having commands to alter the voltage and on the other hand it was connected to solenoid valve where the variable voltage was controlling the air flow operations.

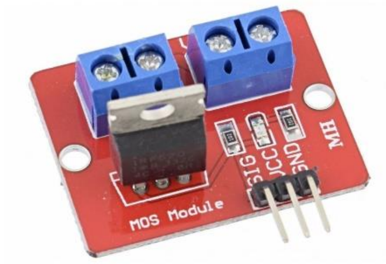

FIGURE 15. MOSFET MODULE

4.4. SD card Module:

SD card module is used to store the data in SD card that was acquired from the suspension system. To apply that data to the testing rig SD card module is connected to Arduino so that Arduino can read that data and control the solenoid valve accordingly.

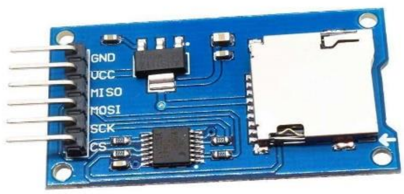

FIGURE 16. SD CARD MODULE

4.5. Arduino Mega:

Arduino is used for the coding of the whole data implementation system. Arduino mega was used in our case as the data that was to be applied consisted upon more than 250 values. It was connected with SD card module from where it read the data and on the other side it was connected to the MOSFET module to which it was commanding the control of voltage which ultimately controlling the air flow in solenoid valve.

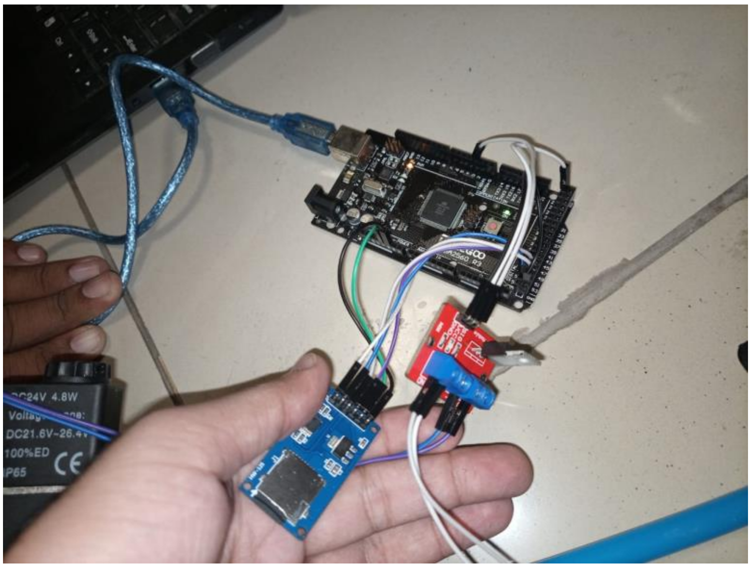

FIGURE 17. ARDUINO ASSEMBLY

4.6. Flow chart of data implementation

Data was stored in SD card which was to be read by Arduino. This data was read by Arduino, and it controls the voltage flow in MOSFET module. MOSFET module was further connected to the solenoid valve and solenoid valve controls the air flow according to the voltage variation. This air flow is responsible for the movement of pneumatic cylinder arm.

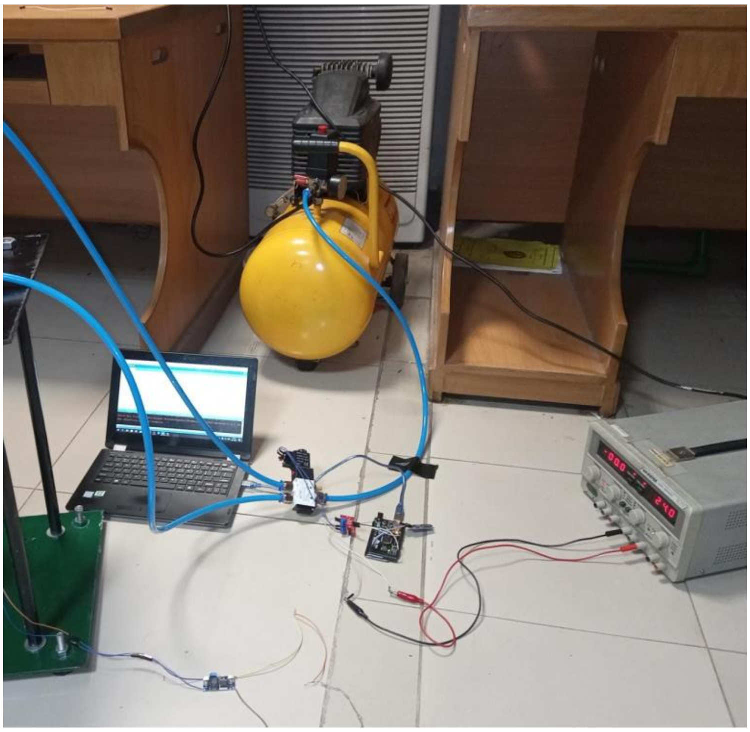

FIGURE 18. DATA APPLICATION SETUP

The flow chart of the whole process is given below.

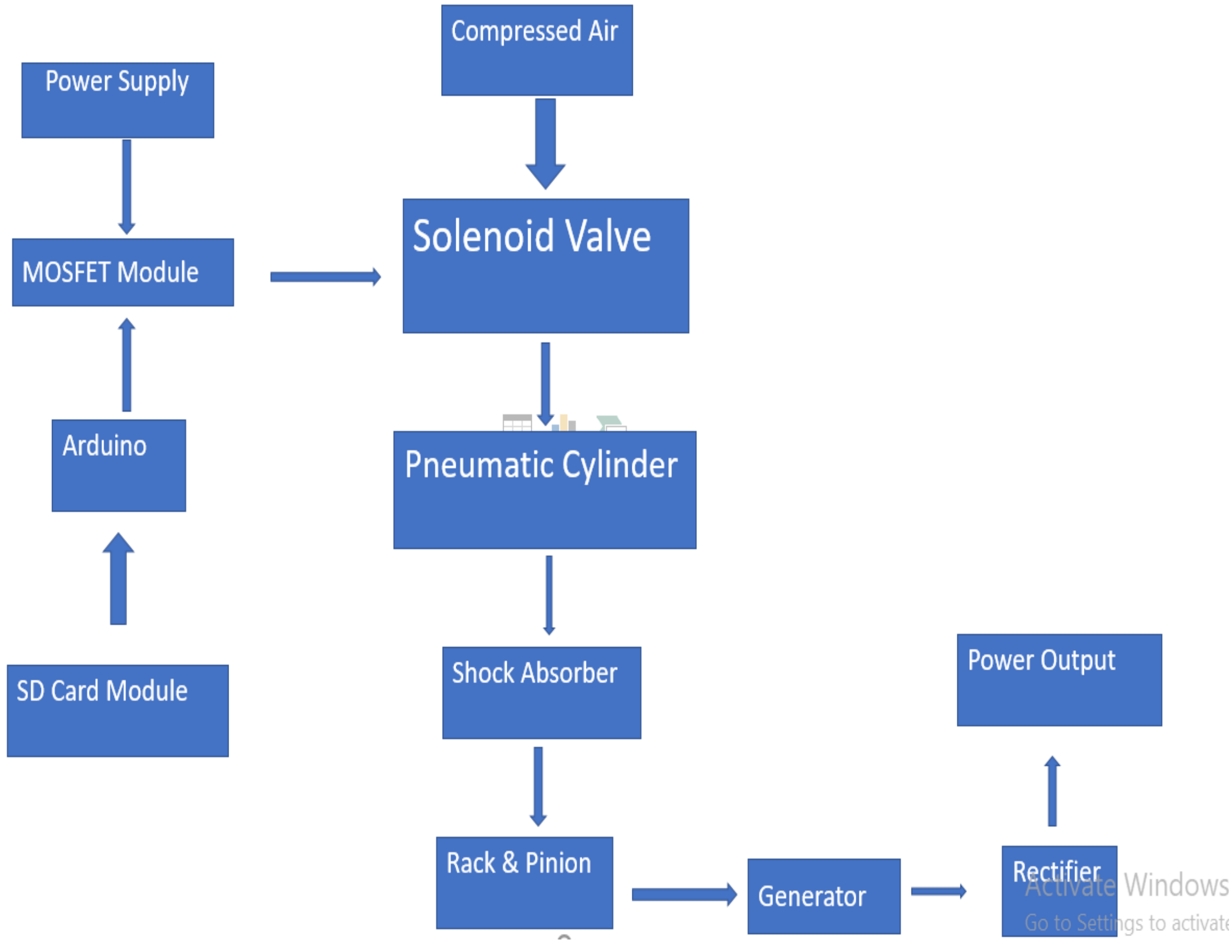

FIGURE 19. DATA APPLICATION FLOWCHART

5. Results and discussions

The data that we acquired from the road is applied to the testing rig to find out the power that could be harvested from the suspension system of the motorcycle. The data when applied to the testing rig along with the power harvesting mechanism, gives the voltage generated and by storing that voltage in the excel by using Arduino, following results were noted. The root mean square (RMS) voltage is maximum when the motorcycle is being driven on the rough road and is coming out almost 18 volts. The power when calculated using the simple formula of P=VI comes out about 9.5 watt on a highway. The amount of power that could be harvested from the shock absorber depends on the speed of the motorcycle as well. With the increase in the speed of the motorcycle, the amount of harvestable power would be increases.

TABLE 1. VOLTAGE RESULT TABLE

Properties	Highway	Street	Rough Road
Maximum Voltage (volts)	23.427	24.339	25.614
RMS Voltage (volts)	16.125	16.356	18.042
Current (amps)	0.1	0.1	0.12

5.1. Effect on the Suspension Stiffness:

The change in stiffness of suspension system was calculated before and after the addition of power harvesting mechanism. For that purpose the whole setup was under the application of force and the shock deflection was measured. It comes out that the deployment of mechanism increases the stiffness of system with 1.4% which is acceptable.

Without Mechanism

- Pressure = 2 bar
- Deflection = 33.5 mm
- K = F/x = 29.9 N/mm

With Mechanism

- Pressure = 2 bar
- Defection = 33 mm
- K = F/x = 30.4 N/mm (1.4% increase in stiffness)

5.2. Conclusions:

Purpose of the research is to give a proof of concept that energy harvesting from suspension system is possible and it can be useful in powering the auxiliaries of automobile. We did this experiment on a motorbike as we have limited resources when it comes to application of data on the testing rig. Power generated was 9.5watts on a single shock absorber of a motorcycle. As an average vehicle weight around more than 10 times of a bike's weight and the amplitude of vibration of vehicle suspension is greater than that of bike. So, it can be concluded that the power generation with this mechanism on a vehicle will provide a considerable amount of energy. That energy can be very useful in hybrid cars or EVs. If added with the Regenerative braking system this power can further enhance the fuel average of automotive machines.

5.3. Future recommendations

- Future research should focus on deploying this mechanism on a vehicle.
- A high-power low rpm generator will be more effective for power output.
- Power output from suspension and regenerative braking system must be coincided for battery charging.

6. APPENDIX A

Arduino Code for Data Implementation

```
#include <SPI.h>
#include <SD.h>

int addTerm = 0;

const byte chipSelect = 53;
String parameter;

byte line;
const byte totalLines = 20; // How many files needs to be used from each file
int theArray[totalLines];          // Array to store values of 1st file
int theArray2[totalLines];         // Array to store values of 2nd file
int theArray3[totalLines];         // Array to store values of 3rd file
byte count = 0;

int array1Min = 1500;       // Minimum value from array 1
int array1Max = 0;          // Maximum value from array 1

int array2Min = 1500;       // Minimum value from array 2
int array2Max = 0;          // Maximum value from array 2

int array3Min = 1500;       // Minimum value from array 3
int array3Max = 0;          // Maximum value from array 3

int delayValue = 150;       // Delay value in milliseconds

int timeDifference = 300;   // time difference in max and min value
const byte actuatorPin = 3; // Actuator is connected at PWM pin 3
```

```
const byte voltageReadPin = 0;  // Use analog pin 0 to read voltage generated
void setup()
{
  Serial.begin(9600);
  pinMode(actuatorPin, OUTPUT);   // Set actuator pin as output
  pinMode(voltageReadPin, INPUT); // Set the voltage read pin as input
  analogWrite(actuatorPin, 0);    // Initially turn off actuator
  while (!Serial);
  Serial.println("Initializing SD card...");
  if (!SD.begin(chipSelect))
  {
    Serial.println("Card failed, or not present");
    while (true);
  }
  Serial.println("card initialized.");

  File myFile = SD.open("street.txt");
  if (myFile)
  {
    while (myFile.available())
    {
      char c = myFile.read();
      if (isPrintable(c))
      {
        parameter.concat(c);
      }
      else if (c == '\n')
      {
        theArray[line] = parameter.toInt();
```

```
      parameter = "";
      line++;
      count += 1;
      if (count >= totalLines) {
        count = 0;          // Reset Count
        myFile.close();
        break;
      }
    }
  }
}
myFile.close();

// Read 2nd file
line = 0;
count = 0;          // Reset Count
myFile = SD.open("highway.txt");
if (myFile)
{
  while (myFile.available())
  {
    char c = myFile.read();
    if (isPrintable(c))
    {
      parameter.concat(c);
    }
    else if (c == '\n')
    {
      theArray2[line] = parameter.toInt();
      parameter = "";
```

```
      line++;
      count += 1;
      if (count >= totalLines) {
        count = 0;          // Reset Count
        myFile.close();
        break;
      }
    }
  }
}
myFile.close();

// Read 3rd file
line = 0;
count = 0;          // Reset Count

myFile = SD.open("Road.txt");
if (myFile)
{
  while (myFile.available())
  {
    char c = myFile.read();
    if (isPrintable(c))
    {
      parameter.concat(c);
    }
    else if (c == '\n')
    {
      theArray3[line] = parameter.toInt();
      parameter = "";
```

```
      line++;
      count += 1;
      if (count >= totalLines) {
        count = 0;          // Reset Count
        myFile.close();
        break;
      }
    }
  }
}
myFile.close();



// Uncomment these lines if you want to check the values
Serial.println("Reading 1st file");
for (int i = 0 ; i < totalLines; i++) {
  if (theArray[i] < array1Min) {
    array1Min = theArray[i];
  }
  if (theArray[i] > array1Max) {
    array1Max = theArray[i];
  }
  Serial.println(theArray[i]);
}
Serial.println("Done");
Serial.println("\nReading 2nd file");
for (int i = 0 ; i < totalLines; i++) {
  if (theArray2[i] < array2Min) {
    array2Min = theArray2[i];
  }
```

```
    if (theArray2[i] > array2Max) {
      array2Max = theArray2[i];
    }
    Serial.println(theArray2[i]);
  }
  Serial.println("Done");
  Serial.println("\nReading 3rd file");
  for (int i = 0 ; i < totalLines; i++) {
    if (theArray3[i] < array3Min){
      array3Min = theArray3[i];
    }
    if (theArray3[i] > array3Max){
      array3Max = theArray3[i];
    }
    Serial.println(theArray3[i]);
  }
  Serial.println("Done");
  String msg = String(array1Min) + "\t" + String(array1Max)  + "\t" + String(array2Min) +
"\t" + String(array2Max) + "\t"  + String(array3Min) + "\t" + String(array3Max);
  Serial.println("Min Max Values");
  Serial.println(msg);
  // Wait for 10 seconds before starting actuator
  Serial.println("Actuator Will start in 10 seconds");
  Serial.println("Processing 1st file");

  for (int i = 0 ; i < totalLines; i++) {
    delayValue = map(theArray[i], array1Min, array1Max, 100, timeDifference+addTerm); //
map the value on time
    digitalWrite(actuatorPin, HIGH);  // Turn on actuator
    delay(delayValue);                    // Before processing next value wait for milliseconds
    digitalWrite(actuatorPin, LOW);  // Turn off actuator
```

```
    delay(delayValue);                    // Before processing next value wait for milliseconds
    Serial.println(delayValue);
  }

  digitalWrite(actuatorPin, LOW);  // Turn off actuator
  Serial.println("Done 1st file");
  Serial.println("Actuator Will start again in 10 seconds");
  delay(10000);                           // Before activating actuator for 2nd file wait for 5 seconds

  Serial.println("\nProcessing 2nd file");
  for (int i = 0 ; i < totalLines; i++) {
    delayValue = map(theArray2[i], array2Min, array2Max, 100, timeDifference+addTerm); //
map the value on time
    digitalWrite(actuatorPin, HIGH);  // Turn on actuator
    delay(delayValue);                    // Before processing next value wait for milliseconds
    digitalWrite(actuatorPin, LOW);  // Turn off actuator
    delay(delayValue);                    // Before processing next value wait for milliseconds
    Serial.println(delayValue);
  }

  digitalWrite(actuatorPin, LOW);  // Turn off actuator
  Serial.println("Done 2nd file");
  Serial.println("Actuator Will start again in 10 seconds");
  delay(10000);                           // Before activating actuator for 2nd file wait for 5 seconds

  Serial.println("\nProcessing 3rd file");
  for (int i = 0 ; i < totalLines; i++) {
    delayValue = map(theArray3[i], array3Min, array3Max, 100, timeDifference+addTerm); //
map the value on time
    digitalWrite(actuatorPin, HIGH);  // Turn on actuator
    delay(delayValue);                    // Before processing next value wait for milliseconds
```

```
    digitalWrite(actuatorPin, LOW);  // Turn off actuator
    delay(delayValue);                    // Before processing next value wait for milliseconds
    Serial.println(delayValue);
  }
  digitalWrite(actuatorPin, LOW);  // Turn off actuator
  Serial.println("Done 3rd file");
}

void loop()
{
}
```

7. References

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