Energy Harvesting From Suspension System of Vehicle

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ISLAMABAD

SEPTEMBER, 2021

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A thesis submitted in partial fulfillment of the requirements for the degree of

MS Mechanical Engineering

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Declaration

I certify that this research work titled "*Energy Harvesting from Suspension System of Vehicle"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Acknowledgements

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.

I am profusely thankful to my beloved parents who raised me when I was not capable of walking and continued to support me throughout in every department of my life.

I would also like to express special thanks to my supervisor Dr. Najam ul Qadir for his help throughout my thesis.

Finally, I would like to express my gratitude to all the individuals who have rendered valuable assistance to my study.

Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment.

Abstract

For us humans main source of energy for past many years have been fossil fuels. As the population of world is ever increasing so is the consumption of fossil fuels. Due to the limited sources of fossil fuels their life has always been concern for humanity as fossil fuels are very dense energy source therefore are mostly relied by humans. With continued depletion humanity shall need either to find alternate sources or to increase efficiency of existing systems such that fate could be prolonged. Another concerning situation associated with the use of fossil fuels is the effect on the environment. Fossil fuels when burnt release emissions which have proved to be harmful to the atmosphere. These effects include, but are not limited to, global warming, acid rain and ozone depletion. All three have direct impact on the human life. My effort in this regard is to use the mechanical energy of the suspension system of vehicle to remove load of alternator from the engine to increase efficiency of engine. Harvesting energy from suspension system of vehicle shall be a viable option as energy generated is essentially lost to environment as heat which is of no use. Suspension has been essential part of vehicle for ages now. Along with the essential use for providing comfort and reliability, suspension will now be giving energy output. Internal combustion engines are not highly efficient. Petrol engines have an efficiency of about 25% while diesel engines are only 35% efficient which is quite limited. This means larger portion of the energy stored is being wasted as heat and other forms of energy. Though efforts are being made to improve efficiency yet no major breakthrough has been achieved in the field. In my work I shall be using vibrational energy of the suspension to generate electricity for the vehicle so that load on engine of the alternator could be removed. When vehicle moves there will be motion in suspension system which will have air pump attached. Due to motion air shall be pumped and stored into container which will have non return valve on inlet and pressure relief valve on the outlet. Non return valve will not let air escape while pressure relief valve will only open at set pressure which is required to operate next in line component piston. Piston cylinder assembly will be used. Piston shall have rack attached in the place of connecting rod. Rack in turn will rotate a pinion which shall be attached with a generator thus energy generation cycle will be complete. Energy generated shall then be used to power components of the vehicle and also recharge battery for starting of the vehicle.

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CHAPTER 1: INTRODUCTION

In this research work a method is being introduced so that the auxiliary energy consumption of the vehicle can be compensated by an alternate method rather than to be a load on engine. Thesis will contain components, their usage and methodology to achieve the proposed solution.

1.1 Background

Engine is an invention which has revolutionized the ways of mankind. Things which used to take months are now matter of hours if not minutes. On one hand humans are enjoying the benefits reaped by such marvels of technology and on the other hand usages of these engines have caused an adverse effect on environment due to the source of energy which is fossil fuel. Fossil fuels when burned produce various gases like carbon dioxide, carbon monoxide, NOX etc. These gases are then released into environment and cause global warming, ozone depletion and acid rains.

The main function of engine is to provide power to drive. Specifically engine in a vehicle has main use of delivering power to the vehicle to move but due to comfort and other uses like running pumps for steering braking and driving alternator engine has their loads and powers them too. This certainly means use of available resources elsewhere. If the alternator is removed from the engine and can be powered from another source it would be beneficial as efficiency would be improved.

1.1.1 Usage of Fossil Fuels in Different Sectors

From the global statistics it can be seen that one of the major consumers of fossil fuels is the transportation sector. Further bifurcation reveals that automobiles are then largest consumers of fossil fuels in transportation sector. Though widely believed that power generation sector is largest consumer of fossil fuel a study into consumption shows that 63.7% of world’s crude oil is used by transportation sector. While only 8.5% of the fuel is being used by power sector. Industries are reliant on the transportation sector to provide raw material for processing as well as to take the finished product to the market for the consumer thus making transportation as essential as any major machinery involved in processing or the operators of those machines.

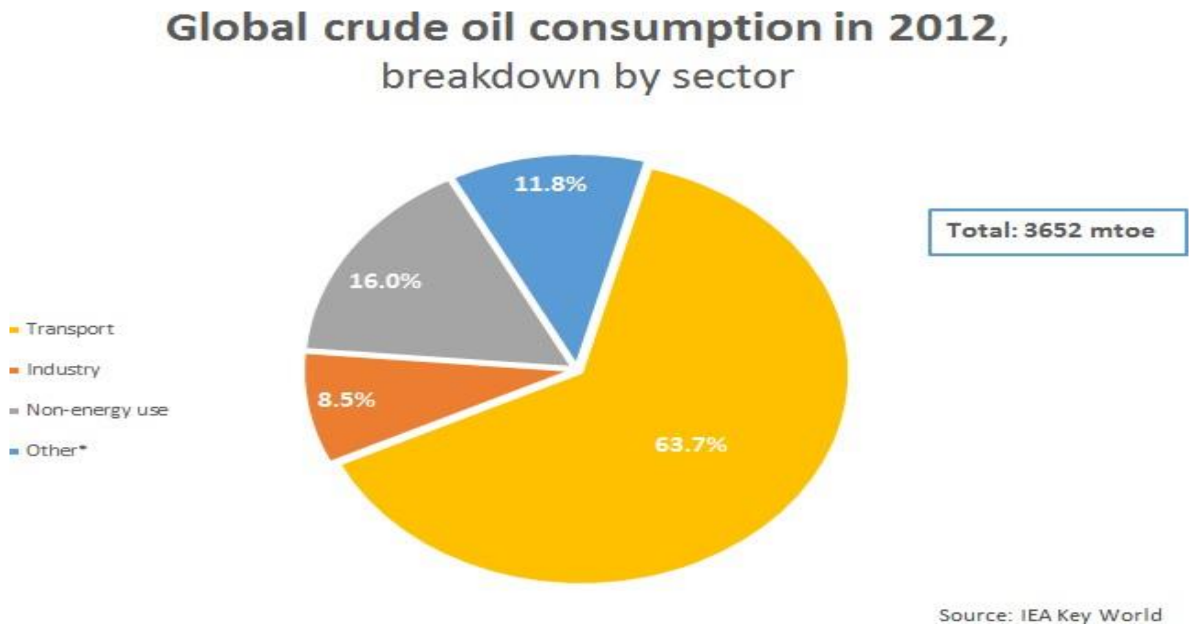

Fig. 1 Global consumption of Crude Oil 2012

The major problem associated with fossil fuels is the product that is received after using it. Fossil fuels are part of the organic compounds family which are long chains of carbon bonded with hydrogen. When the fuels are burned they release energy and gases which include carbon dioxide, carbon monoxide and other gases which due to high temperatures in engines are produced like SOx and NOx. These all when combined are cause of a major challenge that is faced by us humans today is global warming caused by greenhouse gases. Greenhouse gases are causing global warming by essentially making a blanket around the surface of earth. These gases have a specialty of not letting the heat received and emitted by earth to escape thus causing earth surface temperature to constantly increase. Global warming is causing environmental degradation, melting of icebergs, increase of environmental temperature and other problems which in future could be fatal for life form on earth.

Following figure on next page is based on the greenhouse gases produced by different sectors based on their share.

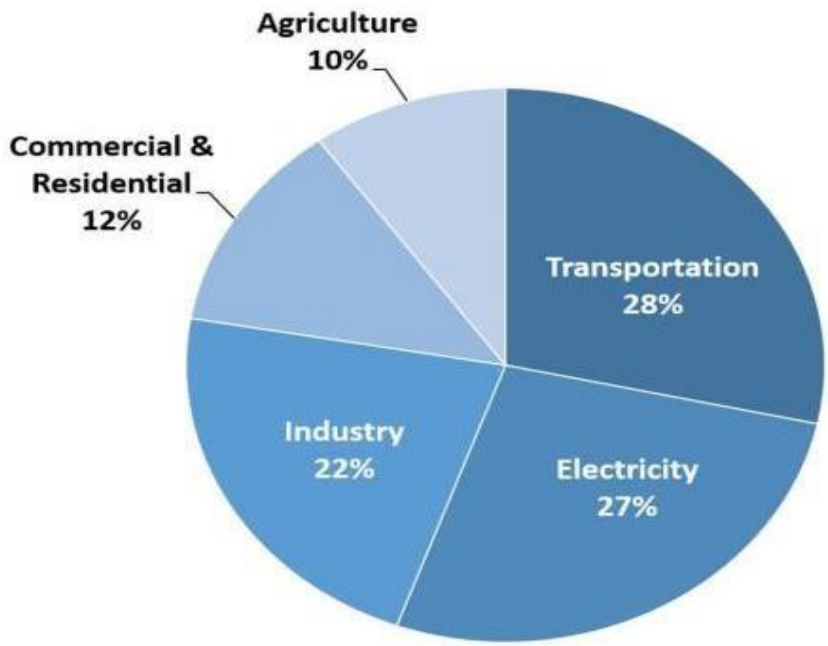

Fig. 2 Sector wise greenhouse gases emission.

From the figure it is evident that transport sector is leading cause of global warming therefore efforts are being made to solve these issues. Research is being carried out throughout the world to tackle the problems.

1.2 Introduction to the Suspension System

An automobile consists of various components which are combined together to give it the shape in which we see it. Different systems which include are the engine, fuel system, transmission, electrical system, cooling and lubrication system, and the chassis, which includes the suspension system, braking system, wheels and tires, and the body. Main reason to have a suspension system as a prerequisite is to enhance life of vehicle and to provide comfort to the occupants of the vehicle. Suspension system can be considered sacrificial as it takes load of the vehicle and provides stability while being under high loads. Loads are due to the weight of vehicle, the occupants, vehicle when passes over the bumps or uneven road and lastly loads due to the acceleration and deceleration. Though working on same principle vehicles have various types of suspensions.

The basic principle on which these systems are based is the Hooke's Law which says "force required to extend or compress a spring by a distance 'x' is linearly proportional". Following is the mathematical representation of the said law is shown below.

Mathematically,

$$F = kx$$

Here,

F= force applied

k= constant of proportionality (spring constant)

x= displacement

Graphically it is as following

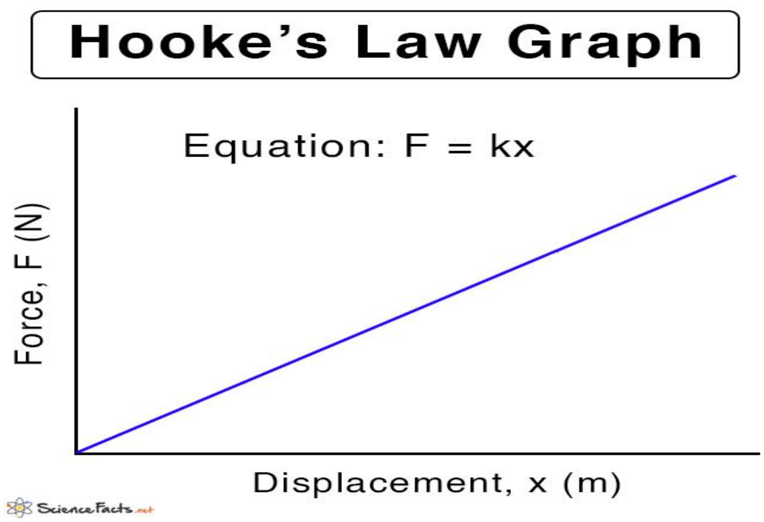

Fig 3 Hooke's Law

1.2.1 Suspension of a Vehicle

For ages now suspension system has been using springs to dampen the effects of the uneven loadings that occur on the vehicle. With advances in technology new types of suspension like air suspension have been developed which are far comfortable than the leaf springs. Due to additional comfort more cost is also incurred and complexity also increases. Widely used types of suspensions include leaf springs, coil springs, hydropneumatic springs and air springs suspensions. Depending on application for instance trucks and load carrying equipment use leaf spring and high end luxury cars have air suspensions. Yet most common type of suspension is based on coil spring along with dampers which have oil in them. Different sizes and orientations of these could be found in the market but end result for them all is same to provide comfort and to bear load.

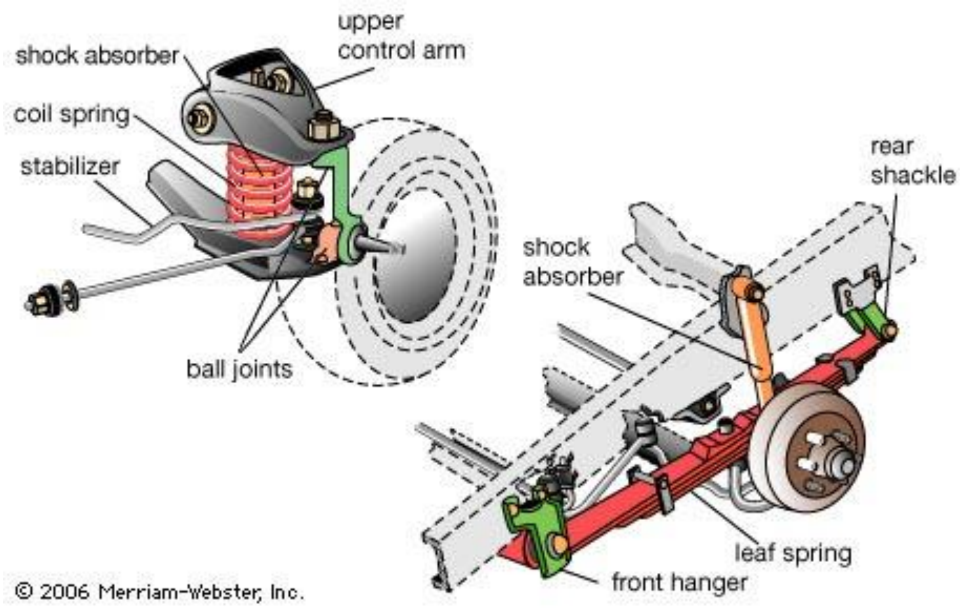

Fig 4 Suspension of a vehicle

Along with comfort suspension maintains contact of vehicle to the ground which is essential for traction and causes the vehicle to move due to friction. Without suspension we would have very bumpy journeys.

1.2.2 Suspension of a Motorcycle

Although the principle of motorcycle suspension is same as that of automobile but here it is to be discussed as the design of our energy harvesting shall be based on a motorcycle's shock absorber. On a vehicle each tire is supported by single spring but for a motorcycle two springs are used in parallel to provide the effect. Reason being both work in parallel to provide the required effects of damping and shocks are supporting tires on both end whereas in the car one side of tires is supported by the body.

Different types of shock absorbers are mounted in motorcycle on front and the rear as different amount of loads are being carried by them. Usually 40% of the load is being carried by front suspension and remaining 60% is being carried out by the rear. Main shock is being handled by the spring to avoid jerks and to smoothen out the jerk dampers are also an integral part of the shock absorbers. Although air and oil whatever a person prefers could be used in the damping device. Most commonly available dampers are that based on oil. Figure below is also a good explanation of parts of shock absorber of the motorcycle.

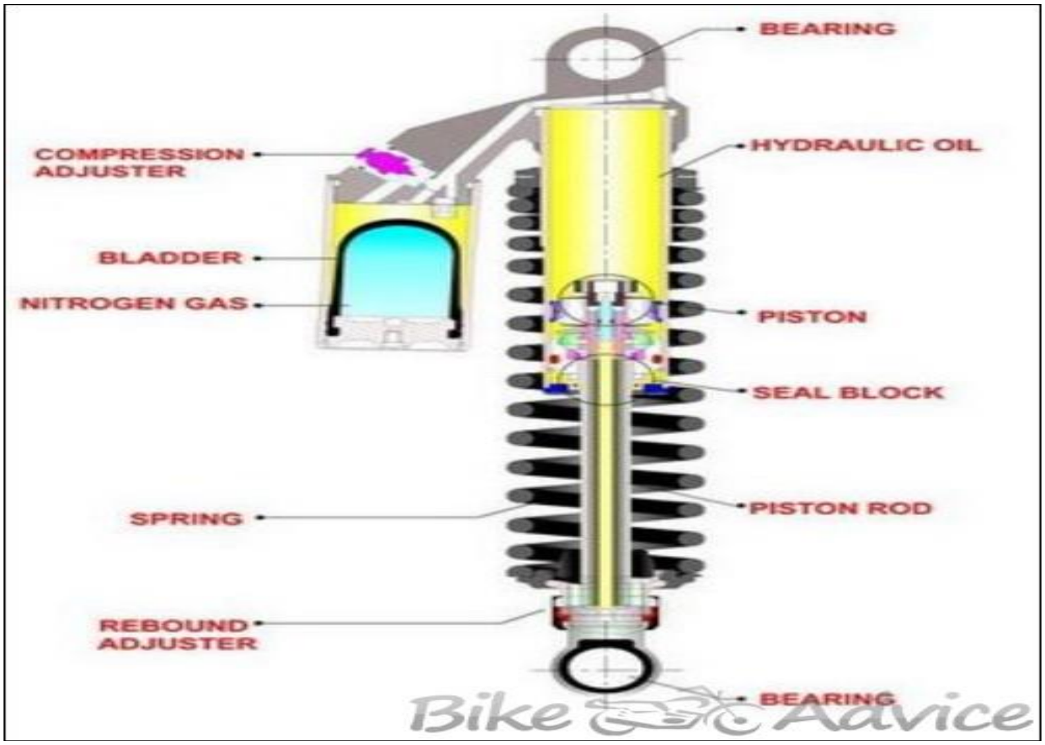

Fig. 5 Shock Absorber of a Bike

Above brief introductions have been made about what shall be our basis of our thesis.

CHAPTER 2: Literature Review

Researchers have been curious for last few years about the losses that occur in the suspension system. As energy is being wasted in the form of heat a potential is seen to harvest energy from the suspension. An approach taken is that with the additional components wasted energy may be used as useful energy.

2.1 Works of Various Researchers

Here results obtained by various researchers would be discussed. Different researchers have taken different routes to achieve same output i.e. electrical energy from the suspension. One of the first researchers to take matters into his hands is Zuo[1]. First electromagnetic shock absorber was developed by him. Although it opened a passage for development but research results obtained by him were limited [2]. Research to produces energy is not limited to the automobiles as Hadas manufactured device that was capable of generating energy in aviation industry from the vibrations [3]. Energy output received from the said device was limited, as only 35 mW could be harvested still it has been considered a milestone for the researchers in the field.

With the passage of time and advances in the field Hendrowati [4] developed piezoelectric vibration energy recovery system. He based the system on mathematical modeling by using one degree of freedom. Further he performed experiments on the vehicle using the developed system. One major observation which is vital for further research and development is that performance of the vehicle was not affected by the system. That is even with the additional components suspension system would work as efficiently as before. On the other hand the output again was limited as only 1.6 mW could be gained.

A comparative study was also carried out between linear and rotational energy harvesting systems by Sultoni [5]. He developed both the systems and then carried out experiments for the comparison. The difference found by Sultoni was astounding as his linear system was capable of producing 90 Watts on the other hand only $2.5x10^{-4}$ Watts was produced by rotational system. From above results it can be seen that linear systems shall be far more beneficial to cater the needs. Linear systems are more comfortable and therefore used in automobile industry but development of such systems is challenge as they are far more difficult to produce than the rotational system. Yet for the researchers of the field this experiment could be considered beacon of light as it gave direction to us as to which path shall we follow.

Another realistic approach was taken by Hashimoto [6] as he used realistic data of the vehicles using the multimode vibrational data. Along with realistic data he also used plate spring of lead zrinconate tittanate (PZT) for the purpose of vibrations. Even with all these approaches used the energy output is not consistent and the problem of limited output stays. Another researcher Zhu concluded from various sources that the mechanical energy produced during the driving by damped vibrations can support the functioning of various systems of the vehicle.

Further experiments were carried out by the but here the classification of roads was done on the basis of road conditions as the smooth roads will have lower vibrations and bumpy roads shall have more vibrations. Roads were then classified in Class A, Class C and Class E. Class A is to be considered road for best driving conditions and Class E as the worst. Power output also has quite a large difference as for Class A road power is limited to 6 μW and starts from 1.1 μW, for Class C road range is 5.2-35 μW while Class E roads are capable of producing output from 13.1 μW upto 130 μW. Therefore it can be expected that Class E roads can be viable to meet the energy requirements for the vehicle.

Shah [7] had experimented in a similar manner depending on the smoothness of the roads and his outputs were astounding. 100 volts were produced at just 10 km/h on bump free road and voltage production increased to 180 volts by increasing speed just to 20 km/h. The design was quite different and he replaced hydraulic oil as the damping agent and used electromagnetic fields of the magnets to receive such results. Another important thing to point out here is the response of the system on bumpy road. Speed was kept same at 10 km/h and 20 km/h but the output increased exponentially to 160 volts and 320 volts respectively.

Zuo analyzed mathematical model for energy harvesting and results suggest that power output could range from 100-400 Watts [8]. On the other hand Zhang introduced new equipment for heavy vehicles with the constraints of maximum acceleration of 0.52 m/s^2 and the maximum load to be 10 tonnes. Power generation was also quite huge with the range of 110 Watts to 200 Watts. This prototype is also considered one of the major works in the field.

Following figure on the next page is a visual representation of works of majority of the researchers as their preferred method of energy harvesting has been electro hydraulic shock absorber.

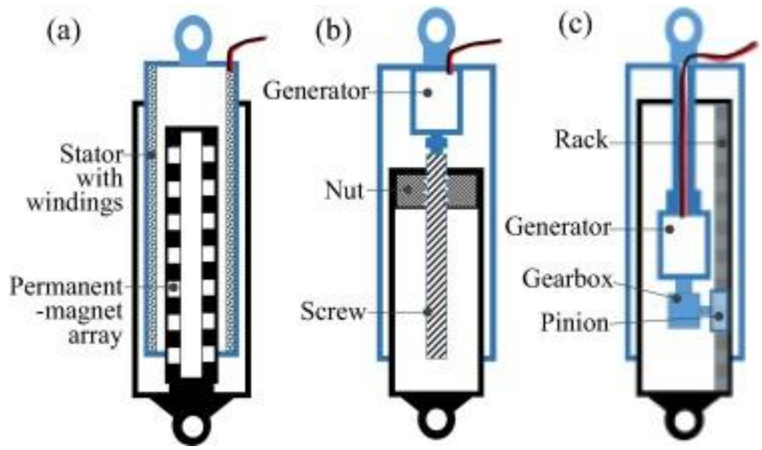

Fig. 6 Electro-Hydraulic Shock Absorber

2.2 Comparison of Researches

Xei [9] designed a hybrid energy harvesting system and concluded that output is based on two parameters that are speed of the vehicle and the smoothness. Speed when increased facilitates to improve the output and smoothness when decreased is helpful for energy generation.

Demetgul [10] then designed a hybrid energy harvesting system which had both the characteristics of hydraulic harvesting system and electromagnetic harvesting system. For damping rates of 0.005 m/s, 0.004 m/s and 0.0045 m/s power output was seen to be 0.25 W, 0.4 W and 0.66 W.

On the next page comparative table for the works of various researchers using hydraulic and mechanical systems is present with respect to the output energy.

Presenter	Mechanism	Output (W)	Energy Harvesting Efficiency
Li and Zuo	Rack and pinion	60–8 4W	N/A
Fang, Guo	Hydraulic system with 4 check valves	6.2 W	16.6 %
Choi, Seong	Rack and pinion	40 W	N/A
Zhang, Zhang	Rack and pinion, two overrunning clutches	4.302 W	54.98 %
Zhang, Huang	Ball screw	11.73 W	N/A
Wang, Gu	Hydraulic system	260 W	40 %
Liu, Xu	Ball screw with two one way clutches	24.7 W	51.9 %
Kawamoto, Suda	Ball screw	44 W	N/A
Zhang, Zhang	DC generator connected to hydraulic actuator	33.4 W	N/A
Shaiju and Mitra	Pump powered by the compressed air	N/A	N/A

Table 1 Comparison of Output Energy by Different Mechanisms

From the above table it can be seen that rack and pinion mechanism has the best efficiency of 54.98 % while hydraulic system can range from 40 to 16 percent. The next table in this regard is for the electromagnetic and piezoelectric systems.

Presenter	Mechanism	Output (V)	Output (W)
Zuo, Scully	Electromagnetic system	10 V	8 W
Goldner, Zerigian	Electromagnetic system	1.3 V	N/A
Gupta, Jendrzejczyk	Electromagnetic system with two layers of magnets	2.52 V	54 W
Xie and Wang	Piezoelectric material	N/A	738 W
Sapin´ski, Rosół	Electromagnetic system	10 V	N/A
Tang, Lin	Electromagnetic system	N/A	2.8 W
Wang, Ding	Electromagnetic system	N/A	24.78 W
Asadi, Ribeiro	Electromagnetic system	N/A	N/A
Chen and Liao	Combination of MR damper	1.9 V	N/A
Sapin´ski, Rosół	Combination of MR damper	2 V	0.4 W

Table 2. Comparison of Electromagnetic and Piezoelectric Experiments

From the table above it can be seen that the most efficient system would be based on piezoelectric material.

Lastly, the energy output from the system depends on large number of parameters and any could affect the output of the designed system. For instance small cars which have 9 degrees of freedom output could be affected by road class, road smoothness, wheels condition, condition of the suspension, interaction of road to tire due to environmental conditions. Due to large parameters trade off in the design are to be made.

Chapter 3: Methodology and Components

Primary goal of the thesis is to provide an alternative to already existing systems for energy harvesting. I shall be using environmentally friendly materials as well as readily available items in the market as new materials and design will take time in development so that the time and money both could be saved.

3.1 Methodology

In this section the proposed method for energy harvesting is going to be discussed. After extensive literature review majority of researchers have focused on piezoelectric option for the purpose of harvesting. The proposed design is going to be a novel approach to the problem and is going to help solve the issues in cost effective and efficient manner.

In energy harvesting system our main aim shall be to capture the potential energy of the shocks that are part of the suspension system. Many different approaches could be taken to use the energy for instance majority of the researchers have used piezoelectric equipment to harvest energy. Although efficient problem with such systems is robustness and another major concern to me is the cost and setting up of such systems. As lots of electronics are involved therefore I am striving to develop such a system majorly based on mechanical devices. My approach based on inputs and lengthy discussions with the supervisor shall be using air as the driving source of the energy generation system.

As the vehicle is moving along on the road variation in road surface causes the suspension of the vehicle to move both in upwards and downwards direction. Driving force for our system is now available. Next step is to use the force into purposeful manner. Air is going to be driving force for our system. Air shall be collected by using a pump. Upward and downward motion of shock shall be mirrored on the pump and pump will start pumping air. Once we start receiving air we shall need to store air for our use. Air will then be collected into a storage tank. Now to stop air from reversing into the pump non return valve (NRV) shall be used. It will allow air to pass in one direction only. Air will be needed at a set pressure for our system to work therefore at the other end of the storage tank we shall use pressure relief valve (PRV) which will release air on set pressure according to our design requirement.

As we now have the driving force for the system next in line is the driven portion of the energy generation system. I shall be using piston cylinder assembly. Air when released at set pressure will force piston to move in the direction of force. The piston shall be attached with a rack rather than a connecting rod. As the rack shall move so will the pinion. The pinion will be mounted on the generator and the movement of the pinion will generate electricity.

When the piston would have moved now is the turn for it to return to its original position to again start the process of energy generation. For the return mechanism of the piston we shall use spring attached. Once we have achieved the required displacement air in the piston cylinder assembly shall be released and spring will move the piston cylinder assembly back to zero displacement.

This shall be a continuous process. The driving force for the system required for the shocks to move up and down can be provided by a cam attached to a motor. As the cam will move it will replicate the motion of shock as on a vehicle to some extent. As the vehicle shocks on the road do not have fixed displacement but here we will have fixed displacements.

In the next section components for our proposed solution shall be discussed in detail.

3.2 Components

To be able to work different components shall work in tandem to produce desired effects. Here we shall require different components. A list of components is as following:

i. Shock Absorber
ii. Metal Plates
iii. Air Pump
iv. Air lines
v. Storage tank
vi. Non Return Valve and Pressure Relief Valve
vii. Piston Cylinder Assembly
viii. Rack and Pinion
ix. Spring
x. Alternator
xi. Battery

These components shall be discussed further in the next headings.

3.2.1 Shock Absorber

Shock absorber [11] is a mechanical device purpose of which is to absorb kinetic energy received and to dissipate in another form of energy. Usually kinetic energy is converted into heat energy and released into the atmosphere. Shock absorbers are integral part of suspension system of automobiles. Other areas of applications are in buildings, bridges, air crafts etc. There they absorb different shock received. For instance during earthquake or high winds, shock absorbers would damp the effects to save buildings and occupants from damage. More common types are twin tube shock absorbers, hydro pneumatic, monotube and load adjusting shock absorbers. Depending on application different type could be used. Shock absorbers are a combination of valves, couplers, springs etc.

Fig.7 Types of Shock Absorber

3.2.2 Metal Plates

As all of the components need to be mounted on certain locations to form a system. Metal plates in our case will be support our system. Mild steel shall be used as it is readily available and shall be able to support our system. Number of plates shall be two. Lower plate will be fixed and upper plate will be free to move with one degree of freedom to give us the desired upward and downward motion for the working of the system.

3.2.3 Air Pump

Pump is a device that moves fluid through system. Usually electrical energy is converted in fluids energy either kinetic or potential depending on the application. Pumps are broadly classified into two categories of dynamic and positive displacement. Depending upon fluid and flow requirements selection of the pumps is made.

For energy generation in our system air will be the working fluid and we require a device which could make air flow. Air pump is a device which is used for pushing air. Different types of air pumps are available for usage. Our requirements are to provide continuous flow for the system and should be mechanically operated. Therefore we shall use handheld pump generally used for sports equipment and bicycles.

Fig.8 Air Pump

3.2.4 Air Lines

As air will be moving in the system at high pressure we shall need special high pressure lines to cater the needs. These lines could be flexible and have different layers inserted to give high strengths to bear loads. Outer layer is polyamide or nylon then next layer is of steel wire as insert and then again polyamide or nylon as inner side. Depending on pressure multiple layers could also be used to enhance strength. A common example of such hoses is on the car's AC compressor high pressure side.

Fig. 9 High Pressure hose

3.2.5 Storage tank

Storage tank is going to be pressure vessel which shall perform various jobs that are to store the fluid at high pressure and storing the energy. Fluid is firstly stored and then released as per requirement of the system to perform the desired task of the system. Storage tank can take specific amounts of fluid and store them at certain pressures. Storage tanks are beneficial to the system as it is energy saving device in the long run. As they can be pressurized smaller pumps could be used and immediate energy availability as pressurized fluid will be available for usage.

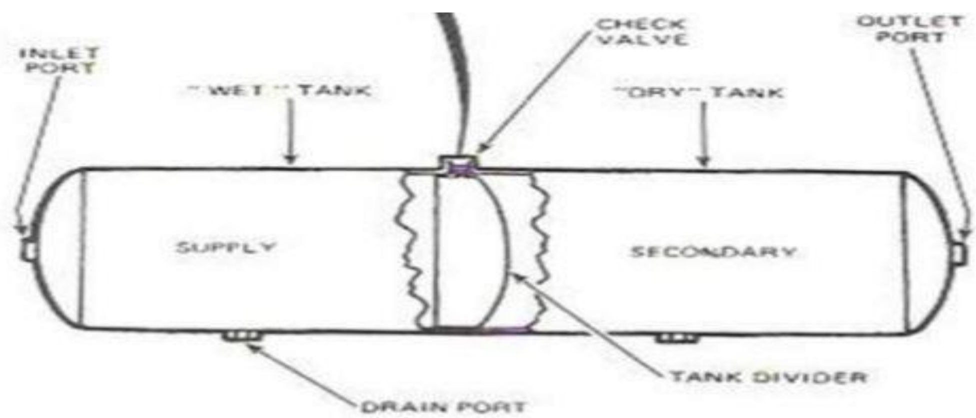

Fig. 10 Storage Tank of Air Brakes

In heavy vehicles air [14] is being used for braking and clutch. Air is first compressed and stored into air tank for working of the vehicle. These come in various sizes and rating and depending on our design we shall make the selection. Truck's air tank may not be necessarily used but our requirement of inlet and outlets is quite matched by them.

3.2.6 Non Return Valve and Pressure Relief Valve

Valve is fluid flow controlling device. It could be used either to control the flow rate or the direction of the fluid present in the system. Valves could be found in the kitchen of one's house to space shuttles. Depending on the application either general or highly specific the cost and modes of actuation differ. Different types of valves include but are not limited to globe valve, ball valve, butterfly valve, diaphragm valve, non-return valve and pressure relief valves. For our application we shall require one non return valve and one pressure relief valve.

Non return valve is also known as check valve and allows flow in one direction only. As we require air to be pumped in on direction and to be stored at high pressure we shall need non return valve. When air is going to be forced into storage tank it will start returning to the pump. Here our non-return valve will stop air from escaping and keep it in our tank. Thus storing the air and not allowing it to escape.

At the inlet of our storage tank we will have non return valve and on the outlet we will have pressure relief valve. This type of valve is usually used as a safety measure in storage tanks as the pressure created in the storage tank should not exceed the rated pressure. Pressure relief valve are rated to certain pressures. When that pressure is achieved valve automatically actuates and pressure is released. We shall be using that released pressure for our system to work.

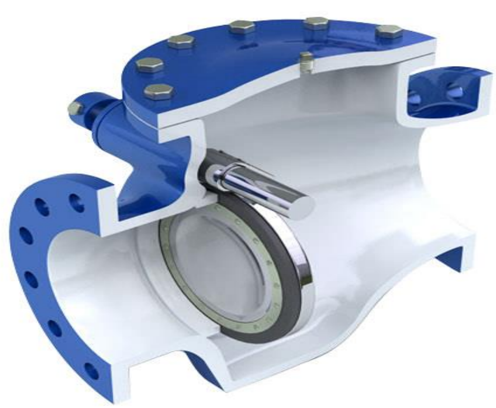

Fig.11 Non-return Valve.

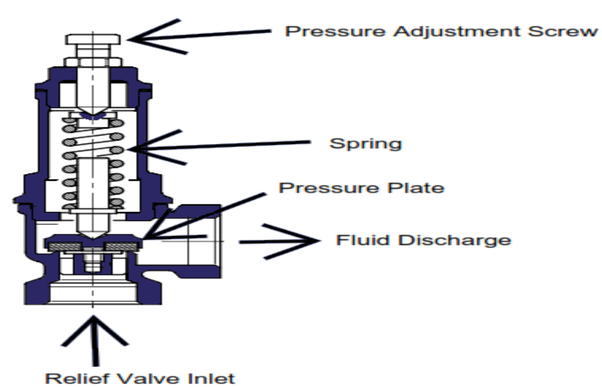

Fig. 12 Pressure Relief Valve

3.2.7 Piston Cylinder Assembly

Piston cylinder assembly is commonly found in engines where high pressure gas pushes the piston to produce work done. In other words piston displaces load applied on it through upwards and downwards motion within a cylinder [12]. Components of the said assembly contain piston, piston rings, cylinder in which piston moves, piston pins, etc. Piston has connecting rod attached to it with piston pin and when piston moves it pushes connecting rod and motion is created which is then transferred to next in line component crank shaft.

In our design driving force would still be gas i.e. compressed air but we shall be removing the connecting rod and replace it with rack. As we do not require rotational motion, translational motion will be provided by rack which is discussed in next section.

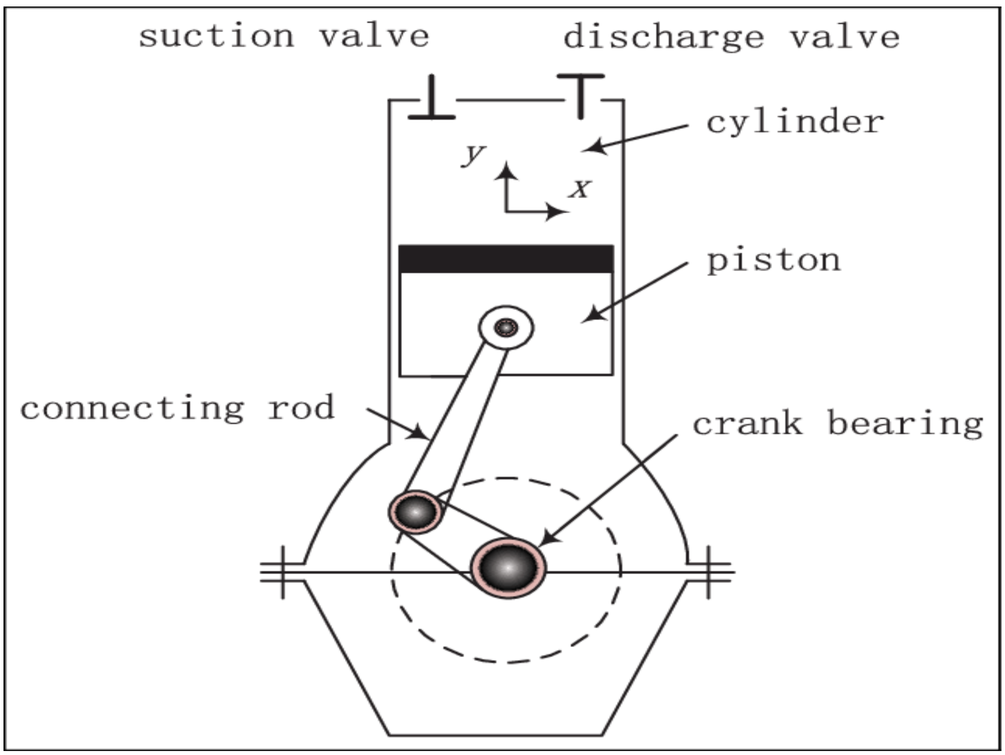

Fig. 13 Piston Cylinder Assembly

3.2.8 Rack and Pinion

Rack and pinion are linear and circular gears combined together to perform tasks. They are used to translate linear motion in rotational motion. One of the most common applications of such system exists in steering system of many vehicles. Rack or pinion any could be the driving gear of the system. Rotation of pinion or rack depending on application will move the system in one direction while in opposite direction will cause reverse motion either rotational or translational.

For our system rack will be driver and pinion will be driven gear. Rack in our system will be attached to piston in the place of connecting rod. As the air in the piston cylinder will push it outwards the rack will also move outwards thus driving the pinion. Pinion when rotating will rotate the generator thus generating energy. As rack will move outward it will facilitate the generation but in the reverse direction it shall resist all the components. Therefore freewheel of a bicycle, that allows cyclist to pedal backward even when cycle is going forwards, shall be used to cater for the problem mentioned above.

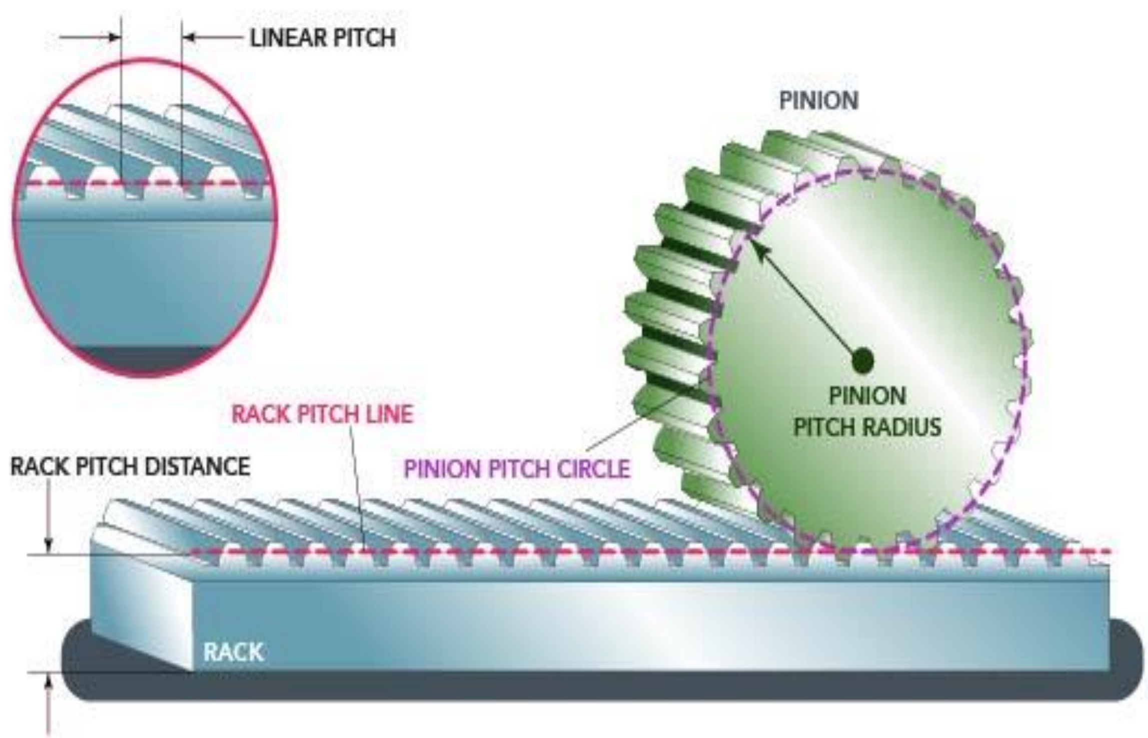

Fig.14 Rack and Pinion

3.2.9 Spring

Any elastic object that stores mechanical energy into potential energy is spring. Typically made of spring steel many designs for spring exist. Most commonly used is helical spring in which coil is rolled to make helical shape like the threads of a screw. Few related things have been added in the beginning.

Piston needs to return to its original state to perform its task again. In our design purpose of springs shall be to provide returning force to the piston and rack. Springs will reduce the complexity and keep our system simple.

Fig 15. Double Hook Helical Spring

Above figure is the type of spring that we shall have in our system.

3.2.10 Alternator

Alternator is the device which caters for the electrical requirements of the vehicle. It converts mechanical energy into electrical energy in the form of alternating current. Alternators have been essential part of the vehicles since 1960 when Plymouth Valiant was first car to have it. Alternators have benefit of working at both higher and lower speeds. In addition to the above benefits it produces more power than comparable size dc generators and does not load the battery for typical operations of the vehicle. This added efficiency comes at a price. These can be expensive and design could be complex. Still benefits reaped overweigh the disadvantages.

Fig.16 Alternator

3.2.11 Battery

Battery is source of electrical energy and usually consists of one or more electrochemical cells. Items that need to be powered are connected externally on the terminal and power is received when the circuit is complete. In our case we are aiming to produce electrical energy from the system. Our choice would be a rechargeable battery so that battery could be used multiple times.

Fig. 17 Rechargeable Battery

Chapter 4: Design and Selection of the Components

In the above chapters we have the reason as well as the guidance for the components that maybe utilized. In this chapter individual items will be designed and selected based on our output requirements. Here our target is to harvest energy from the system.

4.1 Alternator Selection

Alternator is the device that shall be producing the energy in our system so our design parameters will be dictated by the parameters of alternator to produce energy. According to the resources available online the alternator energy production starts at 2500 rpm and above. As we are developing a prototype it shall be difficult to achieve such high rpm. Therefore the alternative is being used which shall be dynamo that is found on the bicycle to give energy to the lights on it.

Working range for a bicycle dynamo is 1000 to 2000 rpm. We shall attempt to achieve these rpms and base our design on the same. Now as we have selected our output device and are aiming to achieve a target rpm of 1600 rpm so that energy could be harvested by the dynamo.

Fig.18 Bicycle Dynamo

4.2 Rack and Pinion

Now we know our target rpm and to transmit force to the dynamo we shall be using rack and pinion. The two design considerations for rack and pinion shall be the tooth pitch and the size of pinion.

The desired RPM of the pinion is 1600 based on the input required by the dynamo. Keeping in view the size and weight considerations of the system we have chosen 2 inch diameter for our pinion and 13 teeth which translates into diametrical pitch of 0.815 cm^{-1} for our pinion. As the pitch of rack and pinion should be similar for operation we now have pitch for our rack. The length however is dependent on the linear movement and the size of piston cylinder. Thus a safe value of 16 cm is taken. The above mentioned values are 4 cm and 10 cm respectively.

4.2.1 Calculations

Following calculations are based on the requirement of our design. Alternator needs to rotate at desired rpm to obtain useful electrical energy from it. Various forces needed to be overcome by released air so that above said could be achieved. Different forces that need to be catered for are going to be calculated and then the working pressure of the system shall be obtained.

Desired rpm = 1600

Pinion Dia = 50.8 mm

Pinion Teeth = 13

Circular Pitch of Pinion= Rack Pitch = 0.815 cm^{-1}

Volume of Gear ≈ $1.013X10^{-5}$ m^3

Mass of Gear = 79.55 g ≈ 80 g

Volume of Rack = 0.00016 m^3

Mass of Rack = 1256 g ≈ 1300 g = 1.3 kg

Mass of Alternator Shaft and Rotor = 200 g = 0.2 kg

Mass of Piston = 100 g

Now using **V=rω**

V=4.256 m/s

For the centripetal force required we shall use:

$$F_1 = \frac{M_t v^2}{R} \qquad M_t = mass\ of\ gear\ and\ shaft$$

$$F_1 = \frac{(0.2+0.08)(4.256)^2}{(\frac{0.254}{1000})}$$

F_1= 199.659 N

Next is interlocking force.

$$F_2 = \frac{M_p v^2}{R} N_t + \mu M_t g N_t \qquad M_p = mass\ of\ rack\ and\ piston$$

$$M_t = Total\ mass$$

$$F_2 = \frac{(1.4)(4.256)^2}{(\frac{0.254}{1000})} 4.06 + 0.6(1.68)(9.81)(4.06)$$

$$F_2 = 4571.682\ N$$

Next shall be the frictional force of the system

$$F_3 = \mu M_t g$$

$$F_3 = 40.14\ N$$

The last force that needs to be calculated is for the return spring. Spring Design is in section 4.5 but the requirement here is for its stiffness.

$$F_4 = -kx$$

$$F_4 = 96.28\ N$$

$$F_T = 199.7 + 4571.68 + 40.14 + 96.28$$

$$F_T = 4907.8\ N$$

Now that we have total force we can calculate the desired pressure at which the system will work for which we shall use following formula.

$$P = \frac{F_T}{2\pi Rh}$$ h=distance travelled by piston

$$P = \frac{4907.8}{2\pi\,(\frac{40}{1000})(\frac{48}{1000})}$$

$$P = 406806\ Pa$$

$$P = 58.24\ Psi$$

From above calculations we now have the operating pressure of the system which is approximately 60 psi.

4.3 Piston Cylinder

Piston shall be forced to move by the pressure of air to produce the energy. Manufacturing of piston is way beyond expertise available in the open market. Finishing of the surface and the tolerances of piston are highly precise and specialized machines and casting equipment is required for such work. On the other hand if we design and ask larger manufactures of such items they will ask for quite a lot of money which will also not be a viable option when considering economics.

Keeping in view above situation piston was then selected based on size and availability in the market. Easily available option was that of a 70 cc bike. It is both common and small in size as per our requirement. Piston size is 48 mm and in the engine it has stroke of 40 mm. Both the values meet our criteria. In addition to that cost of the piston is quite less an replacement when needed shall be available in market promptly.

Fig.19 70 cc Bike Piston

Now that we know the pressure that will be acting on the piston we shall select the components based on the pressure

4.4 Air Storage Tank

Now that we know the design working pressure of our system is 60 psi and we need to store the fluid at least at the said the pressure to suit our requirement. As we know pressure vessels require very high skills and undergo strict quality checks to maintain standards therefore it is suitable for us from safety point of view to purchase available options rather than manufacture. As mentioned earlier air brakes tanks are a suitable option for us because of the high pressure and the way they are built. Normal operating pressure of air brakes is 110 to 120 psi. We can now select the tank of small trucks like Hino 155, Faw Tiger V5 or any other similar vehicle with same working pressures.

4.5 Spring Design

Based on the stroke of the piston which we have kept to 40 mm we need a spring that shall return our piston and rack back to its top dead center so that the cycle of energy generation could be repeated. Following is the design for the spring.

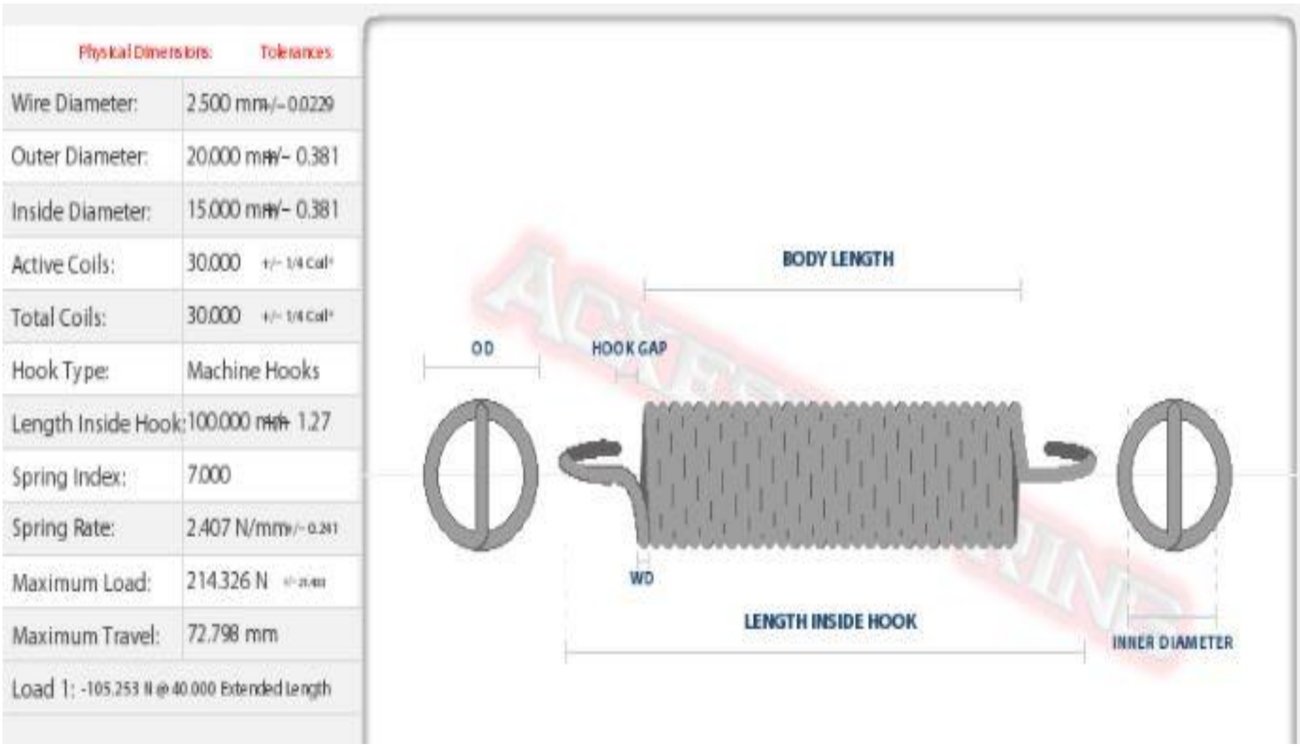

Fig. 20 Spring Design

4.6 Non Return Valve and Pressure Relief Valve

Above mentioned two valves are necessary for working of our system as neither do we want our working fluid to return nor do we want premature release of air. In both the cases we shall be at loss of working fluid and in return loss of energy.

Non return valve spring type of 80 psi shall be used in our design. We have selected this on the basis that air pump that we have chosen creates a pressure quite below it. One thing to mention here is that the storage tank that shall be used has pressure rating of 140 psi which is quite above it therefore chances of damage are quite low and pressure relief valve will also take care of it We have chosen a standard bicycle pump and it can supply a pressure of 160 psi tire pressure when given 300 centimeter cubes of stroke.

Now that we have closed the path for gases to return next is to release gases at the desired pressure. For it spring type pressure relief valve will be used. These valves are automatic and we shall be using the spring type valve due to its easy availability and robust design. Rating of the Pressure Relief Valve is based on the calculations which include different forces that need to be catered for so that energy could be produced. Calculations are in the following section and the rating of pressure relief valve will be 70 psi.

4.7 Shock Absorber and Air Pump Selection

As prototype is being designed and we want good amount of translation to compare to real world applications. Therefore we used a shock absorber from 70 cc bike which is suitable for prototype of such types. Travel for such bike according to manufacturers is up to 90 mm but our requirement is about 50 mm therefore these too are suitable for our use.

Handheld bicycle pump as mentioned earlier can provide pressure of up to 160 psi and our requirement is quite low when compared by available input therefore bicycle pump shall also be suitable for us.

Chapter 5: CAD Model

In this chapter CAD models for the above design and selections are included.

1. Shock absorber and the pump.

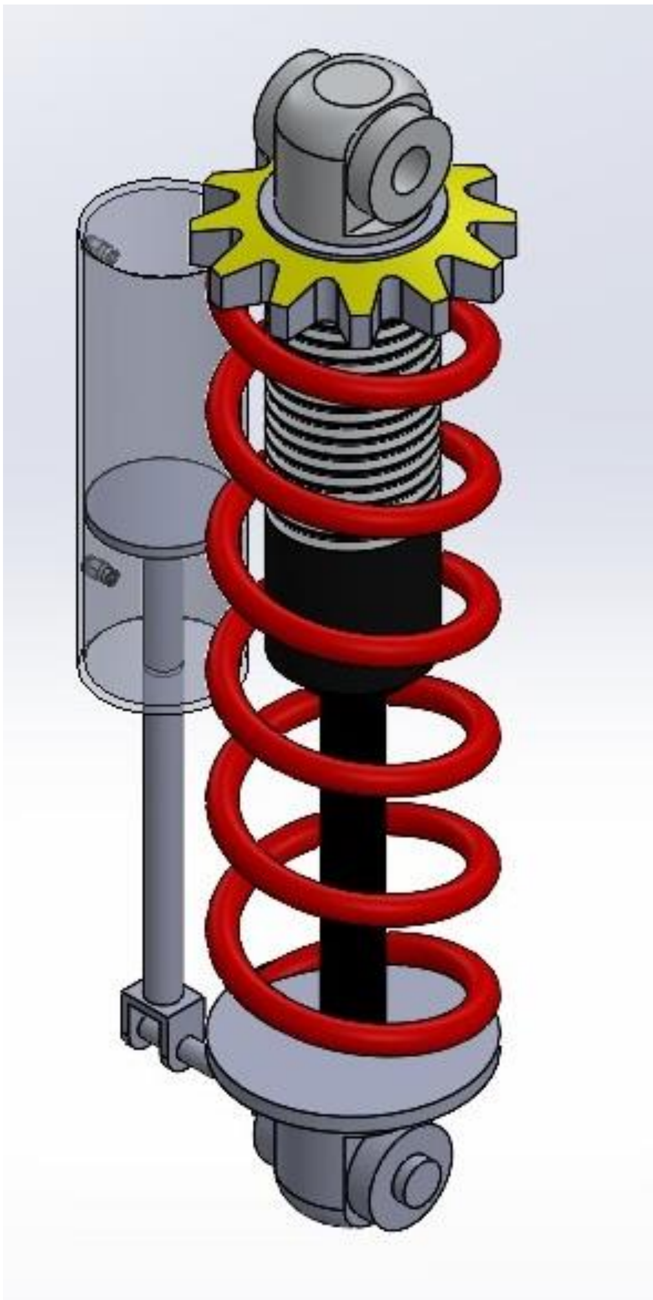

Fig 21 Shock Absorber and Pump

2. Air Tank

Fig 22 Air tank

3. Piston Cylinder Assembly

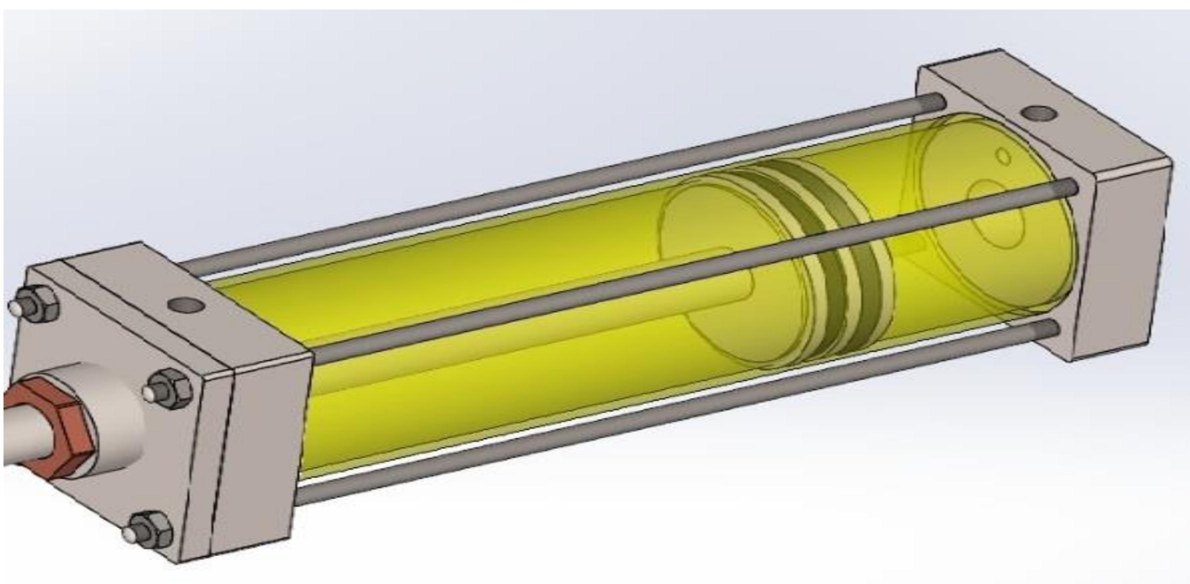

Fig 23 Piston Cylinder Assembly

4. Rack and Pinion with the Dynamo

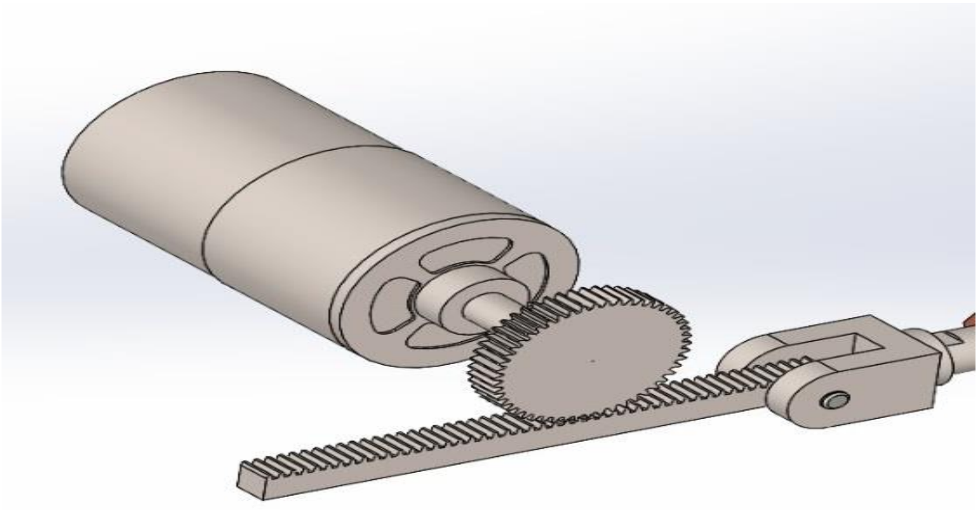

Fig 24 Rack and Pinion with the Dynamo

5. Final assembly

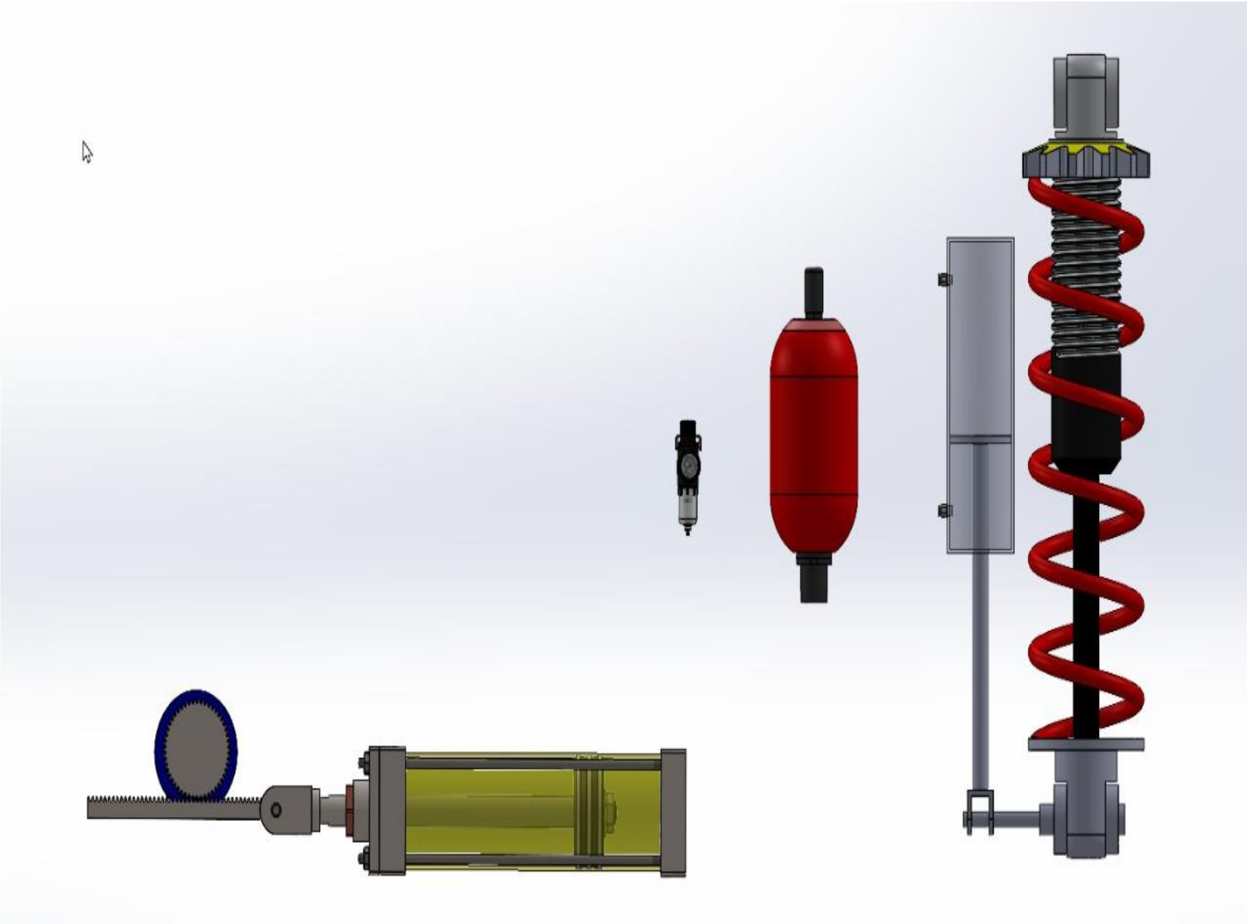

Fig 25 Final Assembly

Chapter 6: Calculations and Results

In this chapter calculation based on the design shall be included. As the system is composed of two steps firstly collection of air at desired pressure and next is the delivery of the said pressure to achieve the goal of harvesting.

6.1 Pressure Calculations

Based on constant amplitude received driven by a motor at certain rpm we shall have following data.

Motor Power = 1 hp

Motor Lifting Capacity = 2446 N

Motor RPM = 1000

Spring Constant for Shock Absorber = 1100 N/m

Displacement = 5 cm = 0.05 m

$$F = -kx$$

$$= 1100(0.05)$$

$$= 55\ N$$

The above force is well below the rating of motor therefore motor is suitable for operation.

Next is the time that shall be needed to achieve the desired pressure of 60 psi.

Air Tank Capacity = 1000 dm^3

Here we shall assume temperature to be constant.

$$PV = pv$$

$$101325(V) = 413685(0.001)$$

$$V = 4.08X10^{-3}$$

$$= 4.08\ dm^3$$

Now as we have the volume that is to be displaced and the rpm of the motor we shall find the strokes which will help us reach the pressure.

Stroke of Pump = 5 cm

Dia of Pump = 2 inch = 5.08 cm

$$Volume\ Displaced = \pi r^2 h$$
$$= \pi \left(\frac{0.0508}{2}\right)^2 (0.05)$$
$$= 0.101 dm^3$$

$$Total\ Strokes = \frac{4.08}{0.101}$$
$$Total\ Strokes = 40.39$$
$$Total\ Strokes = 41$$

As we know the rpm of the motor i.e. 1000 to find the completed cycles within a minute we shall have following.

$$Cycles\ in\ minute = \frac{1000}{41}$$
$$= 24.39$$
$$24\ cycles\ in\ a\ minute.$$

Now these are based on the fixed displacement of the shock. These values can also be compared to the variable displacement of the shock which shall be closer to the realistic output that we shall have when the system is assembled in a vehicle. For which Matlab code and graphs have been added in the annexure A.

6.2 Power Calculations

From the above calculations we now have the number cycles of power that we shall receive. Now based on the results from above we shall calculate the power that shall be available to us.

Presuure = 60 psi

Dia of Piston = 48 mm

Area of Piston = 1.80 X 10^{-3} m^3

$$F = PA$$

$$= 413685(1.80 \text{ X } 10^{-3})$$

$$= 744.639\ N$$

$$Work = Fd$$

$$= 744.639(0.04)$$

$$= 29.79\ J$$

Based on the cycles total energy available in a minute shall be

$$Total\ Energy\ Recieved\ in\ a\ minute = 29.79(24)$$

$$= 714.96\ J$$

Now for the power available

$$P = \frac{Work}{Time}$$

$$= \frac{714.96}{60}$$

$$= 11.92\ Watts$$

Chapter 7: Conclusions

In this system we based our driving force to be air. After the design selection of various components and calculations we shall discuss the conclusions that we could infer from the data.

- The system's energy is based on how quickly the air tank could be filled as in our case air tank could be filled 24 times in a minute.
- More times the air tank fills more energy shall be received. Thus our system will be more efficient on Class C roads as there will be more availability of displacement in short time span.
- Another aspect is the size of air pump the larger the diameter the larger would be displacement of air. For instance as the diameter of the air pump doubles we shall be able to achieve pressure in halve the time thus more energy is available to the system.
- Size of the stroke shall also impact larger the stroke larger the energy present in the system.
- From the available power the system shall be able to support essential functions of the vehicle.

Chapter 8: Future Recommendations

As the above system design is successful in energy generation we can take the design and work on it in following manner. Future work can include developing of system based on above principal which could be used as replacement of the shock absorber of a vehicle and installed in it. This will help us get real time data and see the outputs based on the actual working of the system on the road. Further the system once proven successful by using in car could be patented as this type of system which could be a replacement is not available in the market. Although previous studies have suggested that comfort of the riders should not be affected by adding these types of system to the suspension. But a survey of these systems in vehicle will also be beneficial if this system could be used in real life application

Annexure A

Following is the Matlab code and associated graphs.

Code

```
clc
close all
clear all
P=101325;
r=1500;
d=xlsread('Experimantal Data',1,'C2:C1501');
A=pi/4*0.0508^2;
m=(28.97/1000)*(P*A*d)/(8.314*300);
P2=101325;
for i=1:r-1
    m(i+1)=m(i)+28.97*P*A*d(i)/8.314/300/1000;
    P2(i+1)=m(i+1)/28.97*8.314*300/0.001/1000+P2(i);
end
figure
t=xlsread('Experimantal Data',1,'A2:A1501');
plot(t,d)
xlabel('Time(s)')
ylabel('Displacement')
figure
plot(t,P2/6985,'LineWidth',2)
grid on
grid minor
xlabel('Time(s)')
ylabel('Pressure(psi)')
```

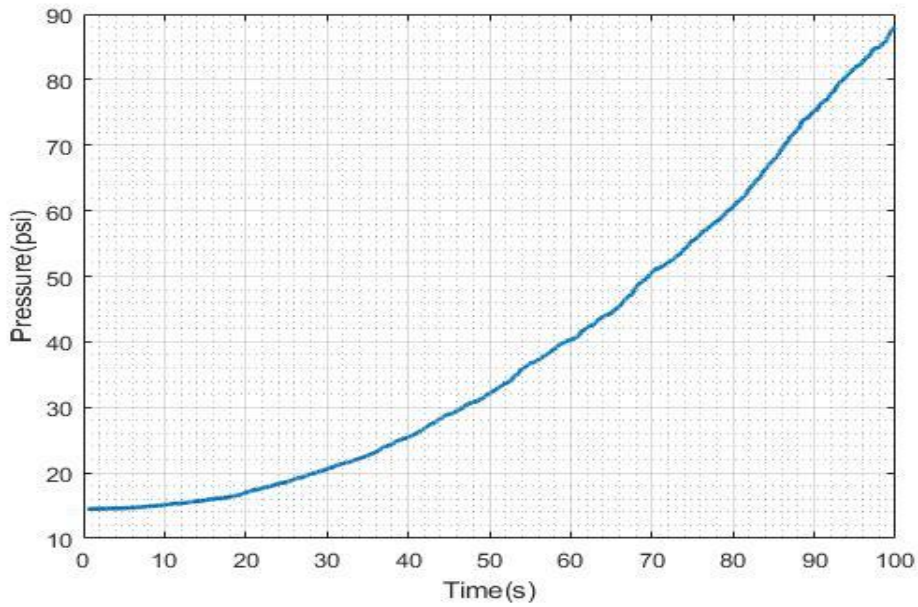

Fig. 26 Pressure vs Time Graph

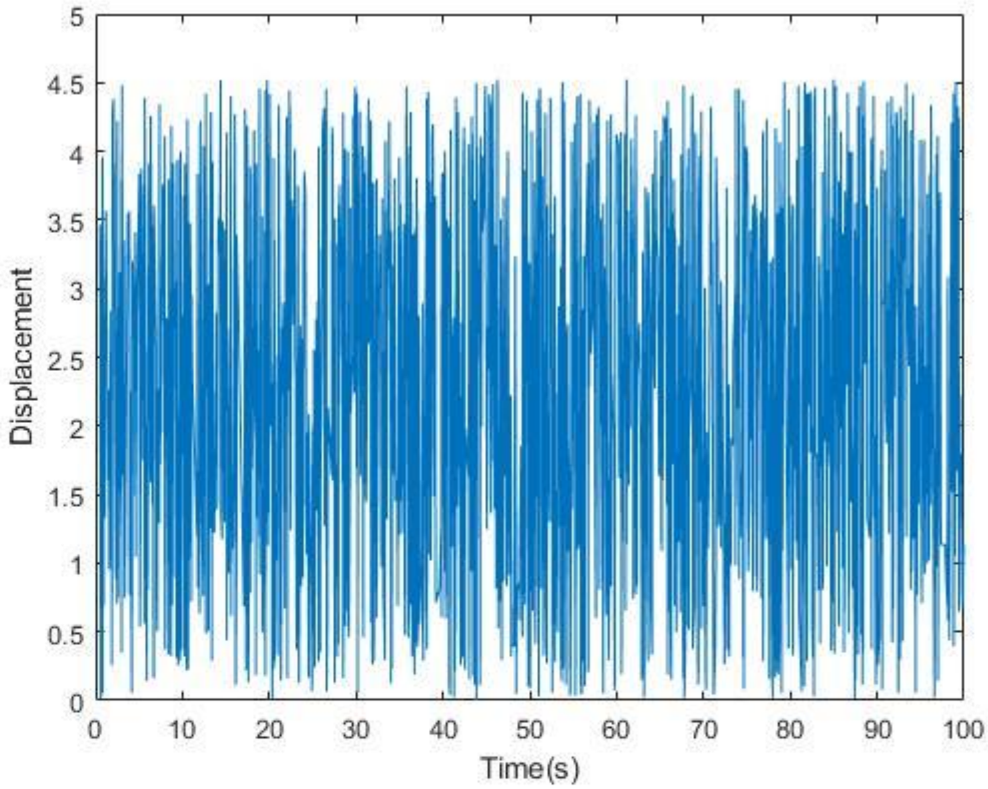

Fig. 27 Displacement vs Time Graph

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