



**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
School of Graduate Energy Center

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**Development and Experimental Investigation of Electricity Generation from  
Hydraulic System Speed Breaker**

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A thesis submitted to the school of graduate studies of Addis Ababa University  
Addis Ababa Institute of Technology in partial fulfillment for the degree of  
masters of Science in Energy Center

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Dec. 2020

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## **CERTIFICATION**

I, the undersigned, certify that I read and here by recommend for the acceptance by Addis Ababa University Institute of Technology, Center of Energy Technology a thesis entitled “Development and Experimental Investigation of Electricity Generation from Hydraulic System Speed Breaker.” This certificate used as a partial fulfillment of the requirement for the Masters of Science in Energy Technology.

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I, Zerom Kahsay, I declare this thesis entitled with “Development and Experimental Investigation of Electricity Generation from Hydraulic System Speed Breaker” is the result of my own work and all source or material used for this thesis have been properly acknowledged. This thesis is submitted in partial fulfillment of the requirement for Master's Degree in Energy Technology at Addis Ababa University and to make available at the university’s Library under the role of the Library. I also declare that this thesis has not been submitted to any other institutions for the reward of any academic degree, diploma, or certificate.

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**Addis Ababa Institute of Technology**

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## **ACKNOWLEDGMENT**

First, I am very grateful to Almighty of God, for his creating environment, continuous and priceless help to accomplish this study because it has not been possible without his blessing and graces. Next to God, I would like to express my sincere gratitude to my advisor Dr. Abdulkadir Aman, who have been supportive in the entire activity and works actively to the completion of this thesis with a continuous follow up. This work could not have been possible without my advisor support and care. Then I would like to express my appreciation to Dr. Solomon T/Mariam, Dr. Kamil Dino and Mr. Futsum for their constructive comment while defending the proposal. I am also like to express my sincere appreciation to Dr. Wondwossen Bogale for his valuable comment and suggestion on electricity generation from speed breaker.

Lastly, I would like to pass my deepest gratitude and appreciation for School of Graduate Energy Center staff, my friends and classmates for their peer review and guidance, without their comment and help this project could not be possible. Lastly, it is impossible to describe in words the love, encouragement and support that I received from my girlfriend and my family.

## ABSTRACT

Energy is among the key elements for the economic and social developments of one country due to that an effort was made to capture the energy wasted when the vehicle passes through the speed breaker. Different mechanisms are used to convert the kinetic energy of the vehicles over the speed breaker in to electricity but in this paper, a prototype is proposed in order to convert the weight of the vehicle in to electricity. This technology is used as energy recovery and reducing dependence on the conventional sources of energy, which focused on the electricity generation from hydraulic system speed breaker. In the rural part of Ethiopia, the generated electricity is used to charge the rechargeable torch for the purpose of light. Also in the urban areas of Ethiopia even there is access of electricity but still the government is unable to supply a steady power. Objective of this research is to increase the efficiency of the existing technology by replacing the traditional one with simple hydraulic type speed breaker. This paper presents detail design and modeling, simulation analysis using ANSYS workbenches and experimental investigation of electricity generation from the prototype by developing a prototype. The new prototype have two-power generation station known as  $PG_1$  and  $PG_2$ .  $PG_1$  Used to convert the weight of the vehicle from 1000Kg to 2000Kg and  $PG_2$  converts from 2000Kg to 7000Kg weight of the vehicle in to electricity using DC generator and stored using battery.

The prototype was tested by applying load (5Kg, 10Kg, 18Kg, 20Kg and 30Kg) on the dome and the average output voltage with load condition (5-watt lamp) is 2.36, 6.46, 12.66, 14.42 and 18.74 volt respectively and the observed average current output is 0.125, 0.156, 0.168, 0.204 and 0.231 Amp respectively. The result power output observed from the prototype with load condition (5-watt lamp) by applying the above weights over the dome is 0.3, 1, 2.1, 2.9 and 4.3 watts and from the simulation result, the power output is 1.03, 2.5, 4.8, 5.4 and 8.3 respectively. Finally, the finding from the prototype of the model and simulation study is discussed in this paper. Therefore, from the result, observed weight of the vehicle applying over the prototype is direct proportional to the power output and this method of electricity generation is eco-friendly to the environment.

**Key words:** *Speed breaker, Power generation, Hydraulic system, Energy recovery and Generator.*

## ABBREVIATION

CRGE	Climate Resilient Green Economy
HSSB	Hydraulic System Speed Breaker
DC	Direct Current
AC	Alternating Current
RPM	Revolution Per Minutes
GVM	Gross Vehicle Mass
ERA	Ethiopian Road authority
PG 1	Power Generation one
PG 2	Power Generation two
CAD	Computer Aid Design
RET	Renewable Energy Technology

## NOMENCLATURE

$W_d$	Work done
$P$	Power
$T$	Time
$F_1$	Force acting on the upper surface of the piston
$F_2$	Force acting on the pinion
$A_1$	Area of the upper piston head
$A_2$	Area of the lower piston head
$D_1$	Diameter of the upper piston
$D_2$	Diameter of the lower piston
$V_1$	Velocity of the fluid on the upper cylinder
$V_2$	Velocity of the fluid on the lower cylinder
$P_1$	Pressure developed in the upper cylinder
$P_2$	Pressure developed in the lower cylinder
$P_{Max}$	Maximum pressure developed
$P_{min}$	Minimum pressure developed

$\sigma_c$	Circumferential stress
$t$	Thickness of the cylinder
$l$	Length
$d$	Diameter
$T_h$	Thickness of the piston head
$L_s$	Solid length of helical spring
$L_f$	Free length of helical spring
$C$	Spring index
$T$	Twisting moment
$\tau_t$	Tangential shear stress
$\tau_d$	Direct shear stress
$K_s$	Spring shear stress factor
$K_w$	Spring wahks shear factor
$\delta$	Deflection of the helical spring
$\theta$	Angular deflection of the spring
$P_c$	Gear circular pitch
$P_d$	Gear diametral pitch
$m$	Module of the gear
$V_r$	Velocity ratio
$N_p$	Number of teeth on the pinion
$\sigma_w$	Permissible working stress
$I$	Moment of inertia
$M$	Bending moment
$W_t$	Tangential tooth load
$\omega$	Angular velocity
$i$	Transmission ratio
$Z$	Number of teeth
$N$	Speed of the gear
$T_e$	Equivalent twisting moment
$M_e$	Equivalent bending moment

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## **CHAPTER ONE**

### **INTRODUCTION**

#### **Sources of power generation and energy mix**

In the present time, energy is the major need for day-to-day human life as well as every sector of economy. Due to continuous increasing population and decreasing non-renewable sources for power generation, provides a need to think on renewable energy resources. Development of alternative energy from sustainable sources such as geothermal, wind, solar and biomass that we can use it repeatedly for a long period have its own advantage for Ethiopia. as well as, energy efficiency measures will be a key part of Ethiopia's energy mix and integrated with the country's new Climate Resilient Green Economy (CRGE) Strategy, which has the ambitious objective of a transforming Ethiopia into climate resilient green economy by 2025[1]. The energy sector in Ethiopia was generally categorized in to two major components traditional and modern (traditional biomass like fuelwood, animal dung, agricultural waste and modern fuels i.e. electricity and petroleum) [1]. In Ethiopia more than 80% of the population is engaged on the small-scale agricultural sector and live in the rural areas[1]. In addition, traditional energy sources represent the principal sources of energy in Ethiopia so that can be a health problem.

Unavailability of sustainable and modern energy in the rural areas has resulted for lack of opportunities on the provision of social amenities such as water supply, health services and educational facilities for that modern energy sources are essential inputs for those. Using clean energy or to reduce carbon emission the government should have to purchase or they have to direct generate power from renewable source. Generating renewable energy that cannot produces greenhouse gas emissions from fossil fuels and reduces the air pollution have environmental and economic benefits and also diversifying the energy supply used to reduce dependence on imported fuels[2]. In addition, it is expected to maximize the number of renewable energy sources and to improve the efficiency of the existing technology of modern energy sources in the future in order to have clean or emission free energy and sustainable economic growth.

However, the energy mix of world or most countries across the world has dominated by nonrenewable energy or fossil fuels this can a major implications for the global climate due to the emission, as well as for health problem. Almost three-quarters of global greenhouse

## Electricity Generation from Hydraulic System Speed Breaker

gas emissions comes from the burning of fossil fuels for to use the energy and now a day 26% of the world electricity comes from renewable energy sources like hydro energy, wind energy, biomass energy, solar energy, geothermal and tidal energy[3]. The world modern energy production from renewable sources was growth up through the year as shown in the figure 1-1 below.

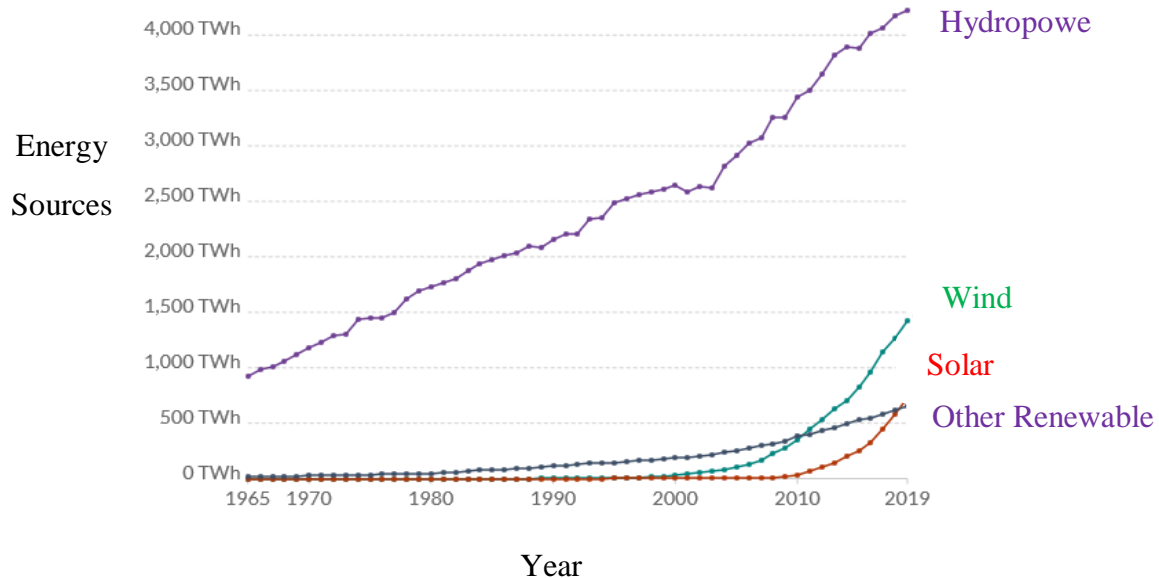


Figure 1-1: World modern renewable energy production by source, (Our world in data on BP statically review of world energy, 2020)

As shown in figure 1-1 hydropower is the largest sources of renewable energy and wind energy is the second largest renewable energy source in the world excluding traditional biomass. Using different sources of energy helps to reduce dependency on a single or limited source also helps to have strength on energy security and used to minimize the risk.

### Introduction to electricity generation from speed breaker:

However, because of the vehicles run with very much high speed on the roads, many accidents take place and to reduce these accidents speed breakers placed on the roads and highways. Therefore, due to the speed breaker a lot of energy of the vehicle was wasted. In addition, the number of vehicles passing over the speed breaker is increasing day by day and it may not reduce with increasing population. Increasing accident and number of speed breakers on roads motivate to manufacture an innovative device, which can channelize the energy of vehicles that will waste on the speed breaker to some useful electricity form. In

## Electricity Generation from Hydraulic System Speed Breaker

this paper, a prototype is proposed to utilize Electricity generation from hydraulic system speed breaker (HSSB) by replacing the traditional speed breakers with some simple mechanism. As vehicles pass over the speed breakers, there is reciprocation motion due to the hydraulic system and it is connect with rack and pinion mechanism to convert the reciprocation motion to rotational motion in to the shaft, which is connected to a generator to generate electricity.



Figure 1-2: speed bump for electricity generation[4]

Utilizing potential energy of the vehicle passing over the speed breaker and converting it to electrical energy that can be store in batteries or we can use it directly for different application. By using HSSB and rack and pinion mechanism in this thesis a prototype is proposed to convert potential energy of a vehicle in to electrical energy and it helps to generate a large amount of electricity. This large amount of electricity can reduces the burden of demands in Ethiopia. The components that will used in the model to convert the potential energy of the vehicle to the electrical energy are hydraulic cylinder, spring, rack and pinion arrangement, shaft, gearbox arrangement, generator and storage.

Recently several models have suggested to convert the potential energy of the vehicle over the speed breaker to electricity generation those researches are listed referance [2], [3], [.4], [5], ,[.6], [7] etc. there are a lot of journals published related to this research title but this system will not work till a vehicle passes on road.

### 1.1. Statement of the problem

As we know, access to energy is among the key elements for the economic growth and social developments of one country. Energy mix or using different source of energy helps to increase generating capacity and reliability but global energy mix is dominated 80% by fossil fuels [11] so the world needs to shift away from that to the energy mix dominated by renewable source of energy. However, Ethiopia have low access to energy, therefore to make our country bright we have to use all the opportunity we have and electricity generation from speed breaker is still in the stage of development. To bring solution for the energy crisis and environmental change the question comes in mind why the researcher cannot focus on the energy recover option, which is like electricity generating from speed breaker.

Most of rural communities in Ethiopia have low access to energy even the cross-country road passes through their village so they are using wood fuel and kerosene for cooking and light purpose and it will cause for deforestation and health problem. Even in the city, there is access of electricity but there is no light always by different causes, in case we need electricity therefore improving the efficiency of the system and implementing it in our country can helps us in order to have high capacity stored energy that can be used for lighting purpose in off-grid community or as a backup power in urban. The aim of this research is to increase the efficiency and maximize the power productivity from speed breaker.

### **1.2. Objective of the study**

#### **1.2.1. General objective**

The general objective of this research is to develop and experimental investigation of electricity generation from speed breaker by replacing the conventional one with simple hydraulic system speed breaker.

#### **1.2.2. Specific objective**

- ✓ Investigate the effect of load on the model, technical design the mechanical parts of electricity generation from HSSB and determining the amount of possible electricity generation from HSSB.
- ✓ Modeling the geometry and simulation analysis to estimate the possible power production from the prototype.
- ✓ Manufacturing a prototype and experimental testing to analyze the power production from the prototype.

### 1.3. Significance of the study

This paper introduces how to generate electricity from hydraulic system speed breaker, which used to recover the vehicle energy wastes on the speed breaker and the output DC power is stored on battery. This is new source of renewable energy technology and this study helps in order to increase the access of energy in Ethiopia if we implement it and also helps to give attention the researcher to improve the efficiency. In addition, this study motivates to use renewable source of energy which is eco-friendly to the environment. In urban areas of Ethiopia 87% of the population has the access to electricity, while in rural areas of Ethiopia electricity access is extremely low which is about 5%. In addition, 83% of the overall population resides in rural areas, they relying on the traditional mechanism like biomass energy sources for cooking and heating[12]. However, in the urban areas of Ethiopia even the access of electricity good but still the government is unable to manage a steady power to them. Therefore, if we apply this mechanism in the entire city speed breakers we can get stored energy for different purpose and the output power from this technology can used for traffic light and streetlight in Addis Ababa. Even in the rural area 95% has no access to electricity even the cross-country road passes through theirs village. Therefore, if we implement this technology on the rural area of Ethiopia the society can get electricity easily for the purpose of light (by charging the rechargeable torch) and mobile phone charging. There is a lot of research published on this area but they are not implement practically if they have enough access of electricity in their country, lack of efficient design on energy conversion system, less quantity of power production from the system, it cannot use in less traffic areas also They have enough access of electricity in their country. Therefore, the objective this research is to design efficient electricity generation from speed breaker and to improve the access of electricity in Ethiopia.

### 1.4. Scope and limitation of the study

This thesis concerns on the experimental investigation by developing a prototype and simulation study using ANSYS workbenches. In addition, the 3D model will be done by solid work software. This study also covers theoretical analysis and modeling of electricity generation from hydraulic system speed breaker using rack and pinion mechanism. This research cannot concern the number of speed breaker in selected site, and how much electricity can generate from those number of selected speed breakers in specific area by considering the number of vehicle. It is in general how to generate electricity from hydraulic system speed breaker by using rack and pinion mechanism. This thesis is also

limited to the weight of the vehicle, if less than the proposed load of the vehicle passes through the hydraulic system speed breaker we cannot generate electricity. This paper included only technical design and modeling, simulation study and experimental investigation but the environmental impact and economic feasibility is not included in the study.

The experimental investigation result was taken by considering  $PG_1$  only as a prototype due to the shortage of raw material and the cost so for the future it is recommended that all parts of the model should have to be develop for the better experimental investigation. During the experimental testing sand is considered as a load but practically it is better to test the prototype by placing on the road and the vehicle have to pass over the dome to analyze the result output.

### 1.5. Thesis Organization

The thesis consists of five chapters, chapter one presents the introduction. Chapter two is review of the theoretical and experimental works done in order to identify the gap and modeling the new proposed electricity generation from speed breaker with better efficiency and increasing the power productivity. Chapter three presents the CAD modeling and material selection, working principal, detailed derivation of the mathematical model, simulation analysis and the experimental work conducted in this study, it includes a detailed description of the experiment setup and the experimental procedures that were done. Chapter four presents the analysis and discussion to the experimental results and simulation analysis and comparison between the experimental results and the simulation result and also comparison with other related works by the output result and the efficiency. Finally, Chapter five provides the conclusions and recommendations.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

In this chapter, literatures on electricity generation from speed breaker using different mechanisms have been reviewed. Moreover, the comparison of different mechanisms used, hydraulic transmission principles review and research gap identification has been done.

#### **2.1. Mechanism of electricity generation from speed breaker**

The idea of basic physics to convert the kinetic energy (the weight of the car over the speed breaker) into electrical energy. A lot of researcher has done different research on this mechanism. First, to make sure South African was implement this technology to light up small villages of the highway[13]. The important point is how we can convert the reciprocating motion that we get from the weight of the vehicle on the speed breaker to the electricity. There are different mechanisms built under a speed breaker and when a vehicle passes through the speed breaker, it generates electricity.

##### **2.1.1. Rack and pinion mechanism**

The system is used to convert the weight of the vehicle in to electricity by using electro-mechanical electricity generating machine. Therefor rack and pinion mechanism used to convert reciprocating motion in to rotary motion[14]. In this mechanism, the top part of the rack is connected with the hydraulic piston head the piston have linear motion due to the vehicle weight acting on the speed breaker. In addition, the lower part is linked with pinion. However, when the vehicle passes over the speed breaker, the rack moves in the downward direction, which is cause to turn the pinion in clockwise direction. The axis of the pinion is coupled with the large gear input to the gearbox.

Ahmad SA, et.al [15] has tested power scavenging from moving vehicles by applying the prototype on the road and the result is discussed clearly, the working principle of the system, its practical implementation, output power calculation and its advantages. The energy generated from speed breaker is enough for lighting street lights during night, by using this arrangement it is possible to store a lot of power. In this mechanism, the linear motion of system is converted to a rotary motion by using a rack and pinion, which is placed in the bottom of speed breaker. The experimental results was taken by placing a power generating speed breaker on the road. When the vehicles move over the speed breaker, voltage is generated and it depends on vehicle speed and vehicle weight. They test the relation between vehicle speed and the voltage generated similarly the relation between

## Electricity Generation from Hydraulic System Speed Breaker

load and voltage at 10km/h speed of vehicle. The output result of the system at 5 Km/h speed of the vehicle is 11.5 V and at 25 Km/h speed of the vehicle is 5.65 V therefore the relationship between the speed of the vehicle and the voltage output is reverse that means the voltage output will decrease during the speed of the vehicle increase. In addition, they got the output voltage in different vehicle weight 1000 Kg vehicle load over the speed breaker generate 13.8 volt and 600 Kg vehicle load generate 11 volt. The result shows that when the load of the vehicle increase the output voltage also increase.

Berlin A, et.al [16] Studied the energy recovery using rack and pinion mechanism the experimental investigation shows that when the weight of the vehicle over the speed breaker increase the efficiency of the system is decrease. Also by keeping constant weight and varying the repetitions or frequency to observe the changes in Voltage produced by the system as more repetitions may allow more rotations in minutes resulting in higher voltages values.

$$\text{Input power} = \frac{\text{mass of the object} \times 10 \times \text{displacement}}{\text{time taken}} \quad \text{eq (1.1)}$$

$$\text{Output power} = \text{voltage} \times \text{current} \quad \text{eq (1.2)}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \times 100 \quad \text{eq (1.3)}$$

The observed result measured from the system by variable weight (50, 75, and 110) Kg with constant frequency the efficiency is 32, 31 and 25% respectively.

By considering different weights with same repetitions and these weights causing displacements in rack to measure the voltage and current produced. The result shows the output voltage and currents are directly proportional to the force applied. Moreover, input mechanical power applied by the vehicle and output electrical power generated by the system also calculated.

It observed from the results that when we consider load with constant frequency the output is lower in terms of voltages but considering constant load with higher frequency, we could get higher voltages, which ultimately results in higher efficiency, this is how we can make system more efficient. Electricity generation through this system is eco-friendly for the environment and help in saving the cost that is spent on electricity for roads in form of streetlights and traffic lights.

## Electricity Generation from Hydraulic System Speed Breaker

Hossain E. et.al [17] recommend the one which is better different mechanism and they analyze the performance of power generation using speed breaker with the help of rack and pinion mechanism. The method provides an efficient way to generate electricity from the kinetic energy of moving vehicles in roads, highways etc. The power developed for one year is 205.2864 MW and percentage of error is 25.9, which is the very compatible with the other mechanism.

$$\text{Percentage Error} = \frac{(\text{Model Power} - \text{Actual Power})}{\text{Actual Power}} * 100$$

When 70 Kg weight of objects push, the speed breaker down the output voltage in the 1<sup>st</sup> pushing force is 30 V and the output current is 0.22 Ampere. The result in the 1<sup>st</sup> pushing output power is 6.6 Watt and 2<sup>nd</sup> pushing output power is 19.08 Watt. After some pushing output, power is 52.49 Watt. The practical results show that proposed project is highly promising for future renewable technology, which can be used as the ecofriendly power generation technology.

Bano S, et.al [18] developed a mechanism how to extract electricity from speed breaker and they developed prototype and implemented on the road under speed breaker. The result shows for one-vehicle passes through it the speed breaker is completely pushed downwards 12 V DC is produced and 100Kg-150Kg weight is required for the complete push of this assembly. The battery used in this system is 12V DC. This battery is connected with the dynamos and whenever there is, a vehicle passed over the speed breaker each dynamo is generating 12V and 6 Watts. This 12V DC is stored in the battery and this is how the kinetic energy converts into electrical energy. They conclude that the efficiency can improve by using shock springs and specially designed rack pinion due to which mechanism is able to bear more heavy vehicles.

Hossam-e-haider M. [19] studied the electricity generation by utilizing the kinetic energy of moving vehicles over speed breaker. The system is designed to extract the kinetic energy of moving vehicles, which converts into mechanical energy through rack and pinion mechanism. A sprocket with 78.1 mm diameter with 22 teeth is used here which is directly connected to the rack and transfer the vehicles wasted energy through a shaft to the large pinion. Also in this proposed design, they have used a 12 V, 6-watt electric dynamo as a DC generator. A prototype model of the proposed system is presented, which needs modification for large scale electricity generation. The experimental investigation is performed by placing the speed breaker arrangement in a pit, different weighted metal

## **Electricity Generation from Hydraulic System Speed Breaker**

pushed on the speed breaker arrangement, the generated current is measured by a multi meter, and power calculated from the respective calculation then the various readings are plotted in a graph. The experimental data shows when 1 Kg of weight applying over the prototype the system generates 0.01962 W power and for 5 Kg of weight the system shows 0.0981 W power. In this experimental investigation, they have tested the result by applying 1-5 Kg of weight and the output power is linear.

### **2.1.2. Roller mechanism**

Roller is fitted in between a speed breaker, and when the vehicle passes over the breaker, it will rotate due to the friction between the tyre and the roller roughness. With the help of chain drive, the rotation of the rollers will rotate the shaft of the generator. As the shaft of the generator rotates, electricity will produced. However, strength of the roller and losses are the limitations of this method which is to be considered.

Bhagdikar P. et.al [9] has designed and developed an experimental study of electricity generation from speed breaker using roller mechanism also attempts to show how energy can be extracted from speed breaker. The mechanism is simple as the vehicles pass over the speed breakers; they spin the rollers which are connected to a generator which in turn generate electricity. The friction force due to vehicle movement acted upon the speed breaker system is transmitted to chain sprocket arrangements.

For testing the setup, a two-wheeler was run over the model at different speeds to get the reading of current and voltage generated under different conditions. It is observed that on moving a small car over the roller, by varies vehicle speed from 10-15 km/hour, the voltage produced is between the range of 3-4 volts. For a single run of a 2 wheeler, 0.06W/tire of power is produced.

### **2.1.3. Crank shaft mechanism**

It is a mechanical part able to perform a conversion between reciprocating motion and rotational motion. It translates reciprocating motion of the speed breaker due to the weight of the vehicle into rotational motion, whereas in a reciprocating compressor, it converts the rotational motion into reciprocating motion. The working principles of crankshaft mechanism is similar to that of rack and pinion mechanism which instead of using rack and pinion as its mechanical parts, it uses crankshaft. Then the rotational motion will transfer to chain and sprocket mechanism or directly to the gearbox and as the power is being

## Electricity Generation from Hydraulic System Speed Breaker

transmitted to the gear drives, the speed is multiplied to a higher speed, which is enough to turn the rotor of a generator to generate electricity.

À DVR, À KPR, et.al [20] Developed a prototype to extract energy from speed breaker and to analyze the result they develop a prototype. The main objective is to design and fabrication of power generation system using speed breaker. The generated power can be used to light up nearby streetlights. Here the reciprocating motion of the speed-breaker is converted into rotary motion using the connecting rod and crankshaft arrangement. In addition, the dimensions of the frame: 3×3×4 feet. Experimental Results; The voltage generated at different load conditions are observed. However, the output voltage of the model is increased as the vehicle load increase. They measure the output voltage at different load by applying 40, 60, 130, 170, 200 Kg load over the speed breaker the output result observed is 6.58, 8.33, 9.45, 10.22, 11.23 voltage respectively.

### 2.2. Comparison of the mechanisms

P. Sharma R. Jain[21] in this review, they have done a comparison between different types of mechanism based on cost, mechanism setup, maintenance, efficiency and design parameters. However, there are different types of mechanism developed for generation of electricity from speed breaker but this comparison included roller mechanism and rack and pinion mechanism. Comparison different types of electricity generation from speed breaker shown in the table below.

Table 2-1 Comparisons of different mechanisms for electricity generation from speed breaker[21]

Parameters		Roller Mechanism	Rack and Pinion Mechanism
1.	Cost	Cheap	Moderate
2.	Mechanism Setup	Very Easy	Difficult
3.	Maintenance	Less Required	Weekly Basis
4.	Efficiency	~50%	~70%
5.	Design	Easy to design	Depends upon weight sustaining capacity

Hossain E. et.al [17] compared the technical merits of various mechanism and they have used different parameters. Based on those parameter from roller and crankshaft mechanism rack and pinion have better advantage for electricity generation from speed breaker.

## Electricity Generation from Hydraulic System Speed Breaker

Table 2-2 Comparisons of different mechanisms for electricity generation from speed breaker[17]

S/N	Crankshaft mechanism	Roller mechanism	Rack and pinion mechanism
01.	High costly	Low costly	Moderate costly
02.	Very difficult to maintenance	Less difficult to maintenance	Moderate
03.	High setup cost	Low setup cost	Moderate setup cost
04.	Poor efficiency	Good efficiency	Better efficiency
05.	Might cause collision	More chance to cause collision	Low chance to cause a collision

### 2.3. Research gap

#### 2.3.1. Lack of efficient design on Energy conversion system

A lot of research published on this area but most of them cannot implement practically because lack of efficient design on the energy conversion system. Overall efficiencies of the system depends on the efficiency of the transmission elements and generator together. If the efficiency of the generator and the transmission elements is each 50%, the two efficiencies are multiplied together to yield the system efficiency ( $0.5 \times 0.5$  or 0.25, or a system efficiency of 25%). A machine's efficiency is the ratio of its output work to the input work. An ideal machine would be 100 percent efficient. All of the input work will be converted to output work. Actual machines lose some input work to friction. To calculate the efficiency of any system by dividing the output work to its input work and multiplying that number by 100. As discussed in the above section review rack and pinion mechanism is efficient as well as cost effective mechanism for generation of electricity from speed breaker. Roller mechanism have less construction cost and mechanism setup is very easy but it have less efficiency due to the friction between the tire and the roller body especially in rainy season the efficiency will decrease. However, among these the popular one Rack and Pinion mechanism is selected for the new prototype because it have better efficiency with less construction cost. The rack and pinion used to convert between rotary and linear motion. By using this method, electricity will be generated throughout the year without depending on other factors and less floor area required.

## Electricity Generation from Hydraulic System Speed Breaker

However, comparatively rack and pinion have better efficiency from the other mechanisms but still the efficiency needs improvement on the transmission system. When the vehicle exerts force on the speed breaker dome, the force is transfer to the rack between this there is a vibration due to unbalanced force that will be a cause for the reduction of efficiency. In this research, the new prototype of power generation is expected to improve the efficiency by using the following three parameters

- a) Smoothness of power transfer,
- b) Sturdiness and ability to take load and
- c) Ease to maintenance.

### 2.3.2. Less quantity of power production from the system

This mechanism to generate electricity is still in the stage of development. In the existent technology based on the following process, we cannot extract the total weight of the vehicle completely according to the arrangement due to high interval of the vehicle weight variation.

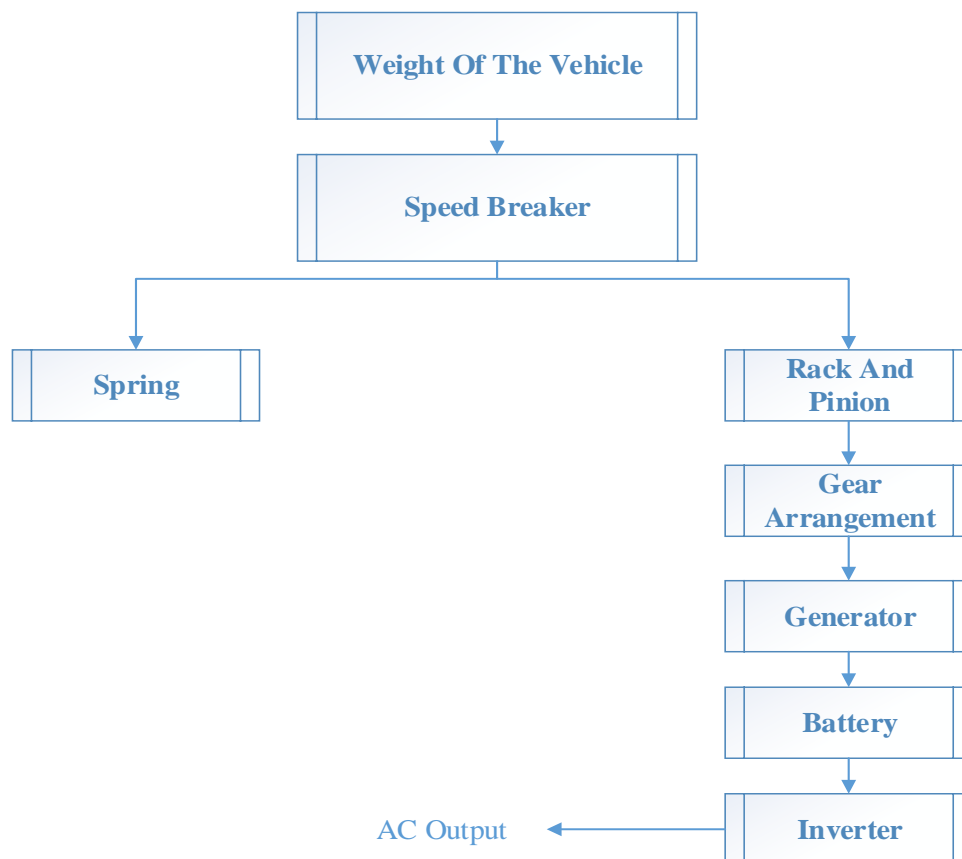


Figure 2-1 Flowchart of electricity generation from speed breaker using rack and pinion

## **Electricity Generation from Hydraulic System Speed Breaker**

When the vehicle exerts force on the dome, the force distributes to the spring and the rack therefore, we have to consider the weight of the vehicle, possible height of the speed breaker, force needed to rotate the pinion and the stiffness of the spring. However, Stiffness of the spring and height of the speed breaker is constant but the weight of the vehicle over the speed breaker dome is vary. The spring will be designed by considering the permissible weight of the vehicle over the dome in order to deflect maximum permissible length of the speed breaker. If the stiffness of the spring is less and heavy vehicle passes through the dome, the speed breaker completely pushed downward at the maximum permissible length of the speed breaker before exerting the vehicle the maximum weight. Therefore, the output power will not increase even the load of the vehicle over the speed breaker increase if the speed breaker completely pushed downward. Not all weight of the vehicle is converting to the electricity by using the existing technology. If the stiffness of the spring is high and the vehicle that have less weight passes through the dome there will be no linear motion on the speed breaker that means there will no electricity generated through the system. By using the existing technology, the quantity of power production is less due to variation of the vehicle passes through the speed breaker and height of the speed breaker the stiffness of the spring is not flexible.

### **2.3.3. Life time of the component and the vehicle passes over the speed breaker**

According to the existing technology, downward motion of the speed breaker is not smooth due to the sudden load applying. Minimizing the vibration on the transmission system can increase the reliability of component. In addition, if it is easy to maintenance and if there exist any problem on the internal part of the machine, it is easily solved. Due to the fast motion and vibration produced on the dome, heavy vehicles can reduce their lifetime. However, this is new technology and renewable source of energy so in this research the main consideration is to increase the efficiency of the model, maximize the power production from the model and to increase the lifetime of the component and the vehicle passes over the speed breaker by using hydraulic system.

### **Energy production from speed breaker**

It contains both mechanical and electrical technologies or it is an electro-mechanical units. Therefore, we can estimate that the power production by the number of vehicle moving on the speed breaker and the weight of the vehicle multiplying by the height of the speed breaker. Electrical power can be produced in many ways, such as from chemical reactions, heat, light, or mechanical energy. However, in this case we are getting energy by converting

## Electricity Generation from Hydraulic System Speed Breaker

the weight of the vehicle over the speed breaker by electromechanical system. The system produces power by providing a rotating shaft, which can exert a given amount of torque on a load at a given RPM. The amount of torque the weight of the vehicle can exert usually varies with RPM. Torque defined as a force around a given point, applied at a radius from that point.

Work is done when a force is exerted to move something over a distance against opposition, such as when the weight of the vehicle over the speed breaker caused to move the speed breaker for x distance. An electrical motor used to drive a machine performs work. Work is performed when motion is accomplished against the action of a force that tends to oppose the motion. Work is the force exerted on an object times the distance over which the force is exerted:

$$W_d = F \times D \quad \text{eq(1.1)}$$

In this case, displacement is Height of the speed breaker. Power is the rate at which work is done. It concerns not only the work that is performed but the amount of time in which the work is done.

$$P = \frac{W_d}{t} \quad \text{eq(1.2)}$$

At constant height of the speed breaker without considering reaction force of the spring and the torque, the expected power output of the system is calculated. Assuming displacement of the speed breaker arrangement is 14 cm, Load of the vehicle exerts force upon the speed breaker 1000Kg – 10000 Kg, Gravity  $9.81 \text{ m/s}^2$  and where 1 vehicle passing over the speed breaker in 1 minute the expected power output without considering the efficiency of the system is

Power developed in one minute = work done /60 second

Work done = weight of the vehicle  $\times$  length of the speed breaker arrangement

## Electricity Generation from Hydraulic System Speed Breaker

### Possible Power develop in One Minutes in different weight

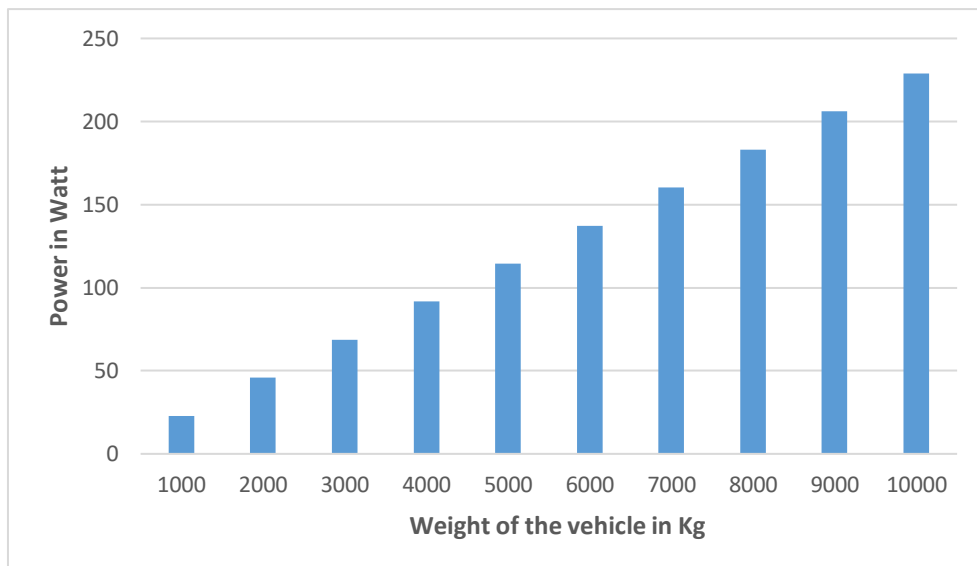


Figure 1-3: load versus power in one minute

The above graph shows when the weight of the vehicle increase the power production also increase. However, the above case is considered only one axle of the vehicle so power output will be multiplied by two if the vehicle have two axle with the same weight but it is without considering the reaction force of the spring, the torque and efficiency.

### Power developed per one day

$$P_{\text{per one day}} = p_{\text{in one munites}} \times 60 \text{ minutes} \times 24 \text{ hours}$$

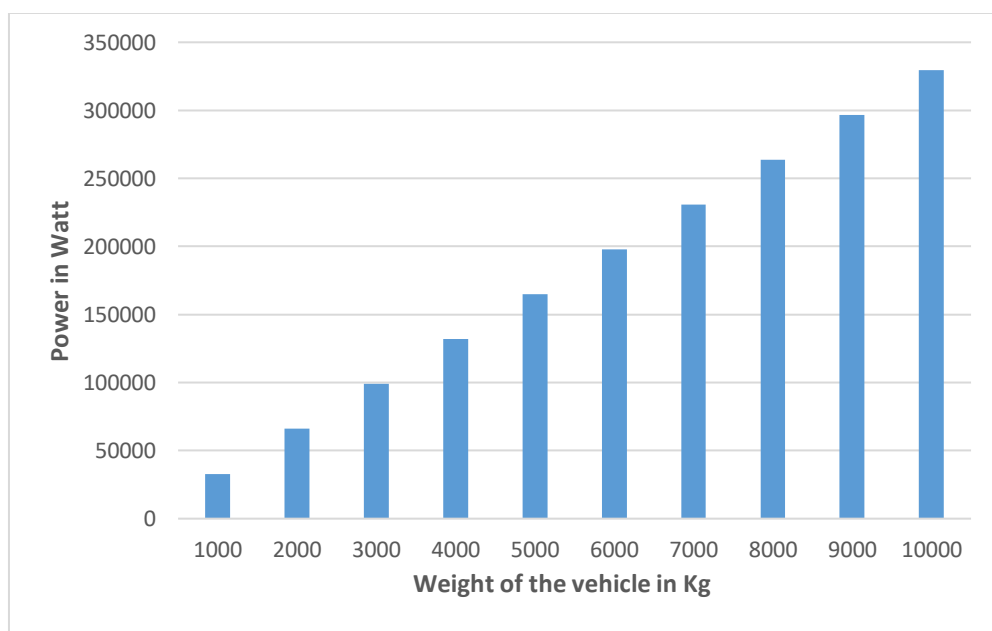


Figure 1-4: power developed per one day

## Electricity Generation from Hydraulic System Speed Breaker

However, if 100 vehicle with load of 10000 Kg passing over the speed breaker in one minute the power output without considering the efficiency of system and reaction force of the spring and the torque is 32.96 Mw power per one day. Therefore, we have to implement this type of technology in busy traffic in order to generate high electricity. Because the concept is that, if the number potential energy of the vehicle moving on a speed breaker increase the production of energy will increase. However, increasing in the height of the speed breaker will increase the production of power even the weight of the vehicle is constant.

### 2.4. Transmission system

In the industry, three methods for transmitting power from one point to another hydraulic transmission or fluid power is through liquids or gas in a confined space, mechanical transmission is through shafts, gears, chains, belts, etc. In addition, electrical transmission is through wires, transformers, etc.

Table 2-3 Comparison of power transmission systems[22]

Property	Mechanical	Pneumatic	Hydraulic
1. Energy transfer element	Levers, gears, shafts	Pipes and hoses	Pipes and hoses
2. Energy carrier	Rigid and elastic objects	Air	Hydraulic liquids
3. Power-to-weight ratio	Poor	Best	Best
4. Torque transmission	Poor	Good	Best
5. Stiffness	Good	Fair	Best
6. Response speed	Fair	Fair	Good
7. Vibration	Fair	Good	Best
8. Dirt sensitivity	Best	Fair	Fair
9. Relative cost	Best	Good	Fair
10. Control	Fair	Good	Good
11. Motion type	Mainly rotary	Linear or rotary	Linear or rotary

The main objective of this research is to increase the efficiency of the system (electricity generation from speed breaker) in order to maximize the power production from the system and to increase the life time of the component and the vehicle passes over the speed breaker

## **Electricity Generation from Hydraulic System Speed Breaker**

by using hydraulic system. In the above comparison to increase the efficiency, we have to consider the property of number 3 to 7 so the hydraulic system have Good efficiency compared to other power transmission system. Also to increase the lifetime of the system we have to select the system that have less vibration and easy to control.

### **2.4.1. Hydraulic transmission system**

The word hydraulics is a Greek word it means water, and originally covered the study of the physical behavior of water at rest and in motion includes the behavior of all liquids, although it is primarily concerned with the motion of liquids. Fluid power is the technology of exploiting the properties of fluids to generate, control and transmit power using flow and pressure of fluids. The fluid can be of any kind. If it is a gas, the technology is called pneumatics. If it is a liquid, the technology is called hydraulics. One of the outstanding features of fluid power systems is that force, generated by the power supply, controlled and directed by suitable valve, and transported by lines, be converted with ease to almost any kind of mechanical motion desired at the place it is needed. Either linear (straight line) or rotary motion can be obtained by using a suitable actuating device. Basic Principles of hydraulics are liquids have no shape of their own, liquids will not compress, liquids transmit applied pressure in all directions, liquids provide great increase in work force.[23]

The hydraulic system uses incompressible fluid, which results in higher efficiency and hydraulic systems employ high-density incompressible fluid possibility of leakage is less in hydraulic system as compared to that in pneumatic system. In addition, the maintenance cost is less and it delivers consistent power output, which is difficult in pneumatic or mechanical drive systems also automatic lubricating provision to reduce to wear. In this new prototype helps in order to have Smooth movement of the speed breaker and it helps to have large load capacity with almost high accuracy and precision and it is easy to control and to have limiting and balancing of hydraulic forces easily performed. [23]

### **Hydraulic Fluids**

The use of hydraulic fluids to generate and transmit power is based upon physical laws, which govern the mechanics of liquids. The hydraulic fluid is an essential and important component of any hydraulic power or control system. No other component of the circuit must perform as many functions or meet as many requirements as the hydraulic fluid.

There have been many liquids tested for use in hydraulic systems. Currently liquids has tested include mineral oil, water, phosphate ester; water based ethylene glycol compounds,

## **Electricity Generation from Hydraulic System Speed Breaker**

and silicone fluids. The three most common types of hydraulic fluids are petroleum-based, synthetic fire-resistant, and water based fire-resistant. In the operation of fluid power systems, there must be a flow of fluid. The amount of flow will vary from system to system. To understand fluid power systems in action, it is necessary to understand some of the characteristics of liquids in motion.[24]

### **Pascal's Law**

Pascal's principle, an experimentally verified fact, is what makes pressure so important in fluids. The following Pascal's principles are related to this research and the model is designed by those considerations.

- ✓ Change in pressure on a fluid is transmitted equally to all points in the fluid and the enclosing surface of the container. This is the principle of the hydraulic press.
- ✓ The static pressure acts at right angles to any surface in contact with the fluid.
- ✓ The external static pressure applied on a confined liquid is distributed or transmitted evenly throughout the liquid in all directions.
- ✓ Pascal also found that the pressure at a point for a static fluid would be same across all planes passing through that point in that fluid.
- ✓ Moreover, Pascal's principle implies that the total pressure in a fluid is the sum of the pressures from different sources.

### **Bernoulli's principle**

In fluid dynamics, Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. The principle is named after Daniel Bernoulli who published it in his book Hydrodynamic in 1738.[25]

- ✓ He showed that as the velocity of fluid flow increases, its pressure decreases.
- ✓ Bernoulli's principle, which states: For the horizontal flow of fluid through a tube, the sum of the pressure and the kinetic energy per unit volume of the fluid is constant

From this principle the prototype have two cylinder (the upper narrow cylinder and the lower wider cylinder) A fluid's speed will increase as it travels through narrower spaces and decrease as it travels through wider spaces.

### 2.4.2. Mechanical Transmission efficiency

Gears, belts and chain are some of the transmission elements used for transmitting power to the required part. Based on the requirement of the application and economic, the designer will choose the transmission needed based on different criteria. Among these transmission system gears are the most effective and efficient transmission with reduced wear and tear if sufficient lubrication is available. It has nearly 100% efficiency in some cases. Used in speed reduction systems especially in gearbox in case of manual transmission. In addition, chains provide greater timing and power transmission in case of medium power transmission. It has sound operation and wear is more. Used in passenger vehicle transmission in operating camshaft, alternator from crankshaft. Belts are efficient in transmitting power. However, maximum wear is possible and belt slip may prevail in case of maximum power transmission.[26]

In case of rack and pinion mechanism for power generation at speed breakers which is implemented in south africa they are used chain drive as a transmission element in this model to improve the efficiency of the system gearbox is used by replacing the chain and sprocket mechanism and over that in order to have smooth linear motion hydraulic system speed breaker is provided.

### Gearbox

A gearbox is two or more gear working together by meshing their teeth and turning each other in a system to generate power and speed [27]. In this case used to increase speed and reduce torque that comes from hydraulic system speed breaker. However to create large gear ratio, gears are connected together to form gearbox. However, the rotational motion input to a gearbox have high torque and low speed, which is used to maximize the input speed and to reduce the torque. Gearbox have better efficiency than the chain drive system and it have large speed ratio. The purpose of a vehicle gearbox is to transfer power from the hydraulic system speed breaker to the generator. Serves the following functions:

- ✓ It used to control the power flow.
- ✓ It used to control the output torque.
- ✓ It used to control the output speed.

Gearbox can also use also in order to have better efficiency and to maximize the power production by using controlling system connected with hydraulic fluid. If more than the allowable weight of the vehicle passes through speed breaker excess pressure is develop

## Electricity Generation from Hydraulic System Speed Breaker

inside the cylinder, there is pressure-setting valve used to push the connecting rod and then the gearbox output speed will be changed. Most of the research on this area chains and sprocket are used to maximize the speed of the pinion and transmit motion and power from one shaft to another. This system transmission is used when the center distance between their shafts is short such as in bicycles, motor cycles, agricultural machinery, conveyors, rolling mills, road rollers etc. The chains may be used for long center distance of up to 8 meters. The chains used for velocities up to 25 m / s and for power up to 110 kW. In some cases, higher power transmission is also possible. chain and sprocket transmission system have disadvantages as if the production cost of chains is relatively high, The chain drive needs accurate mounting and careful maintenance, particularly lubrication and slack adjustment and the chain drive has velocity fluctuations especially when unduly stretched.

### Gearbox efficiency at different speed

Table 2-4 torque speed and efficiency of gearbox [27]

Torque (Nm)	Speed (rpm)	Average Efficiency
5	500	86.87%
5	1000	89.55%
5	2000	87.90%
5	3000	88.62%
5	4000	93.46%
35	2000	97.65%

In order to know the transmission efficiency of gearbox, they build a test measurement system and the result is as shown in the above. Power loss in the gearbox is mostly due to friction between to gear.

### 2.5. Weight of the vehicle

Electricity generation from the speed breaker is vary due to the weight of the vehicle and the weight of the vehicle is influence by the passengers, cargo, even the fuel level. So a number of terms used to express the weight of a vehicle in a designated state. Gross Vehicle Mass (GVM) is the maximum operating mass of a vehicle as specified by the manufacturer including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers and cargo but excluding that of any trailers.

According to the International Transport Forum August 3, 2015, most of the country in Europe permissible maximum weights of Lorries is limited to an overall maximum weight of 44 ton and the weight of the drive axle is 11.5 ton[28][29].

## Electricity Generation from Hydraulic System Speed Breaker

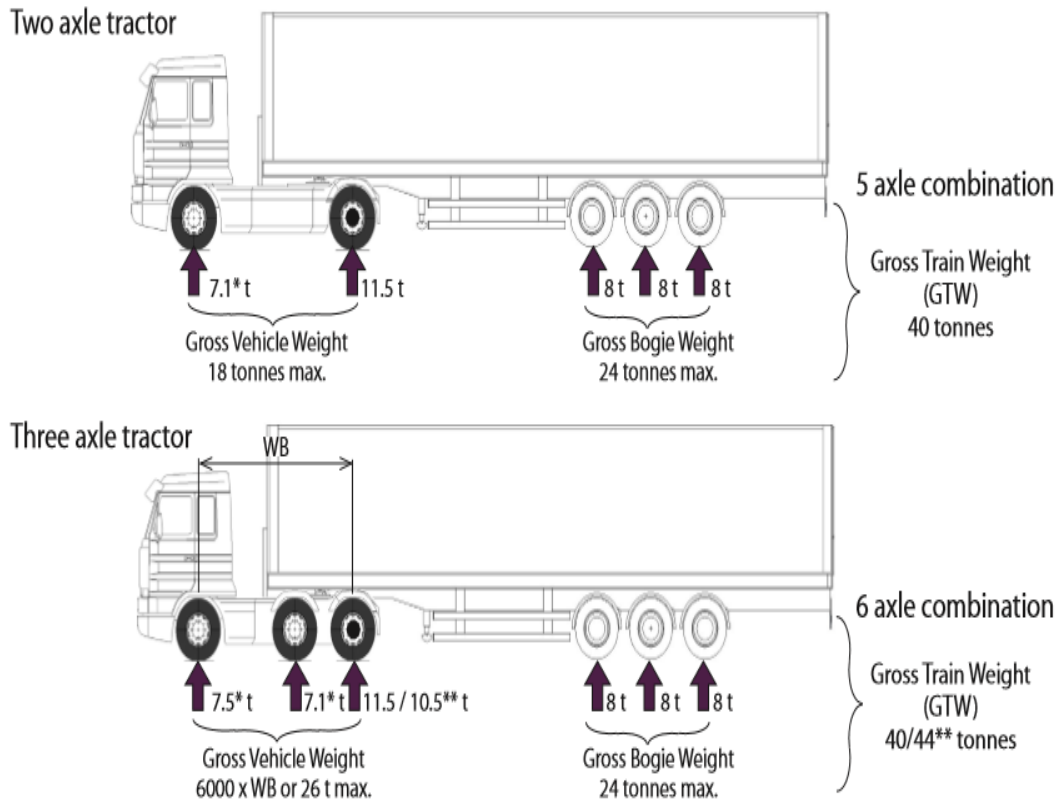


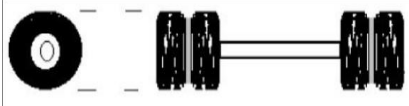
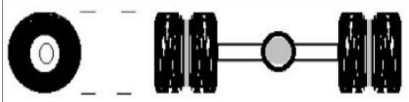
Figure 2-2 distribution on Weight of the vehicle (Source: TATA Technical Information Sheet Axle weights and load distribution 1 October 2013) [28]

Table 2-5 maximum weight of the vehicle (Source: road safety authority Guidelines on Maximum Weights and Dimensions of Mechanically Propelled Vehicles and Trailers, Including Maneuverability Criteria February 2019) [28][29]

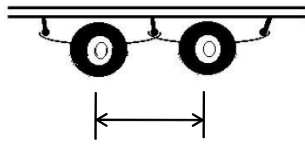
Maximum Weights for Axles & Wheels

DESCRIPTION	COMMENT	MAXIMUM WEIGHT TRANSMITTED	IMAGE
Wheel which is part of the sole driving axle	Whether with single or twin tyres.	5.75 ton	
Wheel which is <u>not</u> part of the sole driving axle	Whether with single or twin tyres.	5.0 ton	

## Electricity Generation from Hydraulic System Speed Breaker

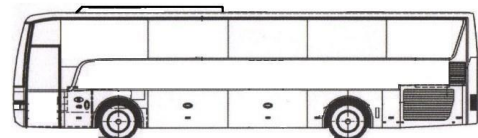
Single axle	Whether with single or twin tyres.	10 ton	
Sole driving axle	Twin tyres.	10.5 ton or 11.5 ton with an air suspension or an equivalent system	

### Maximum Weights for Tandem Axles

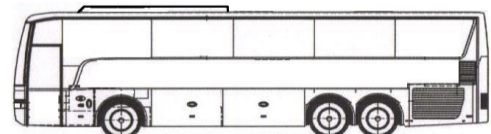
	AXLE SPACING (X)	MAX WEIGHT TRANSMITTED	
Tandem axles of a vehicle or trailer	Less than 1.0m	11.5 tonnes	X Distance measured from center of front to center of rearmost axle
	1.0m or greater	16 ton	
	1.3m or greater	18 ton	
	1.8m or greater	20 ton (For trailer or semitrailer only)	

### Maximum Weights for Two and Three Axle Buses

Two-axle buses 19.5 ton



Three-axle buses 25 ton



Three-axle articulated 28 ton



Figure 2-3 weight of the vehicle (Source: road safety authority February 2019)

Vehicle classification is an essential aspect of traffic volume evaluation (as well as evaluation of equivalent axle loads). The types of vehicles are defined according to the breakdown adopted by ERA for traffic counts: cars; pick-ups and 4-wheel drive vehicles such as land rovers and land cruisers; small buses; medium and large size buses; small trucks; medium trucks; heavy trucks; and trucks and trailers. According to the ERA breakdowns are further simplified for reporting purposes, and expressed in the five classes of vehicles (with vehicle codes 1 to 5) just like the small car (including the passenger cars, minibus with 24 passenger seats, taxis, pick-ups, and land cruisers, etc.). In addition, medium and large size buses above 24 passenger's seats, small and medium size trucks including tankers up to 7 tons load and trucks with trailer or semi-trailer and tanker trailers[30].

### **2.6. Road width**

The widths of vehicle lanes typically vary from 9 to 15 feet (2.7 to 4.6 m). Lane widths are commonly narrower on low volume roads and wider on higher volume roads. The lane width depends on the assumed maximum vehicle width, with an additional space to allow for lateral motion of the vehicle. A lane is part of a roadway that is designated to be used by a single line of vehicles, to control and guide drivers and reduce traffic conflicts. According to the ERA where conditions are severely constrained, lane widths as low as 3.3 meters can be considered, provided that approach speeds are below 80 km/h. In constricted urban conditions on low speed-roadways, lane widths of 3.0 meters should be the minimum adopted[31].

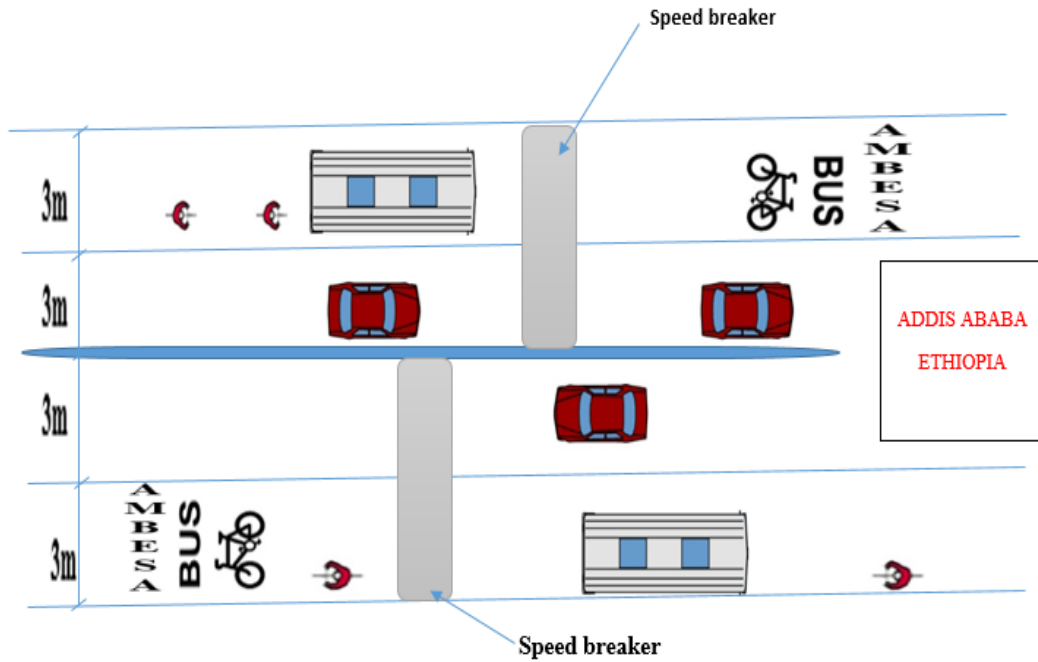
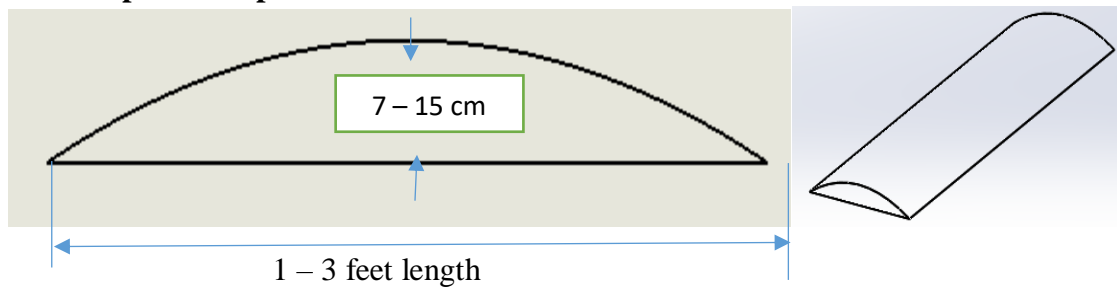


Figure 2-4 road dimension in Addis Ababa

### 2.7. Dimensions of speed breaker

There are different types of speed breakers used to reduce accident/crashes. Among those speed bump and speed humps are suitable for the purpose of electricity generation.

#### a. Speed bump



#### b. Speed hump

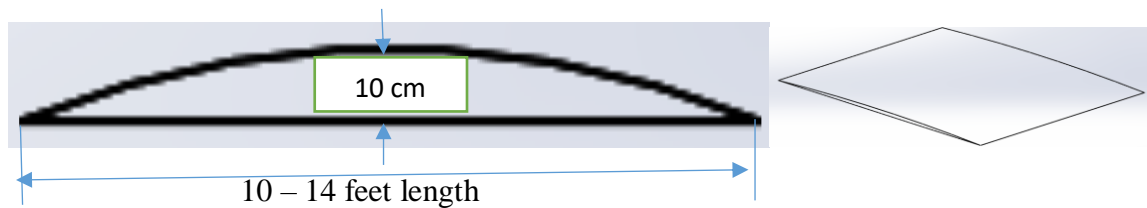


Figure 2-5 speed breaker size[32]

## **CHAPTER THREE**

### **METHODOLOGY**

This chapter used to show the methods involved on the research so it contains theoretical design of the prototype, simulation study for the actual size of the model using ANSYS benchmarks and experimental investigation. Prototype is develop to analyze the result output and to show the mechanism how to convert the weight over the speed breaker to electricity. Three-dimensional drawing of the prototype is designed using solid work software and the performance of the component is simulated using ANSYS benchmarks.

#### **3.1. Modeling**

The target is to convert the energy of the vehicle, which is being wasted everyday on the speed breaker to the electricity for the purpose of different application. The generation of the power from the developed model is depend on the weight of the vehicle, height of the speed breaker, efficiency of all components. Main function of the prototype is to convert from 1000Kg to 7000Kg weight of the axle using hydraulic and electromechanical system. When the height of the speed breaker increase the power productivity also increase but the vehicle wastes extra energy to pass it. Hydraulic system is additional for the purpose of smooth movement to increase the efficiency of the system and force multiplication to produce more torque on the pinion of the power generation. In this case, rack and pinion mechanism used to convert the linear motion of the hydraulic oil to the rotational motion and that rotational motion maximize the speed using the gearbox the output speed will convert to electricity using the DC generator.

#### **Consideration on designing the prototype**

- ✓ To increase efficiency of the energy conversion
- ✓ To maximize the quantity of power production
- ✓ easy to control, flexibility and easy for maintenance
- ✓ life time of the component and the vehicle passes over the speed breaker
- ✓ availability of materials used for the components

The prototype designed to convert from 1000Kg to 7000Kg of the weight of axle but by assuming the weight of the piston 1 and the breaker dome both 1000Kg the working load of the model assumed from 2000Kg to 8000Kg. The diameter of piston 2 is twice of the diameter piston 1 so the torque in the pinion power generation 1 is high due to that the

## Electricity Generation from Hydraulic System Speed Breaker

working load for the power generation 1 is from 2000Kg to 3000Kg. In addition, the working load for the power generation 2 is from 3000Kg to 8000Kg.

Diameter of piston 1 is 1.5m therefore the area is  $1.767\text{m}^2$  and the minimum working pressure of power generation 1 ( $P_1$ ) of the fluid inside the cylinder is 0.011103 Mpa and also the minimum working pressure of power generation 2 ( $P_2$ ) is 0.016655 Mpa.

However, if the load applying over the speed breaker is less than the allowable weight (1000Kg) or if the pressure inside the cylinder ( $P_i$ ) is less than the minimum working pressure of power generation 1, both power generation 1 and power generation 2 cannot generate electricity.

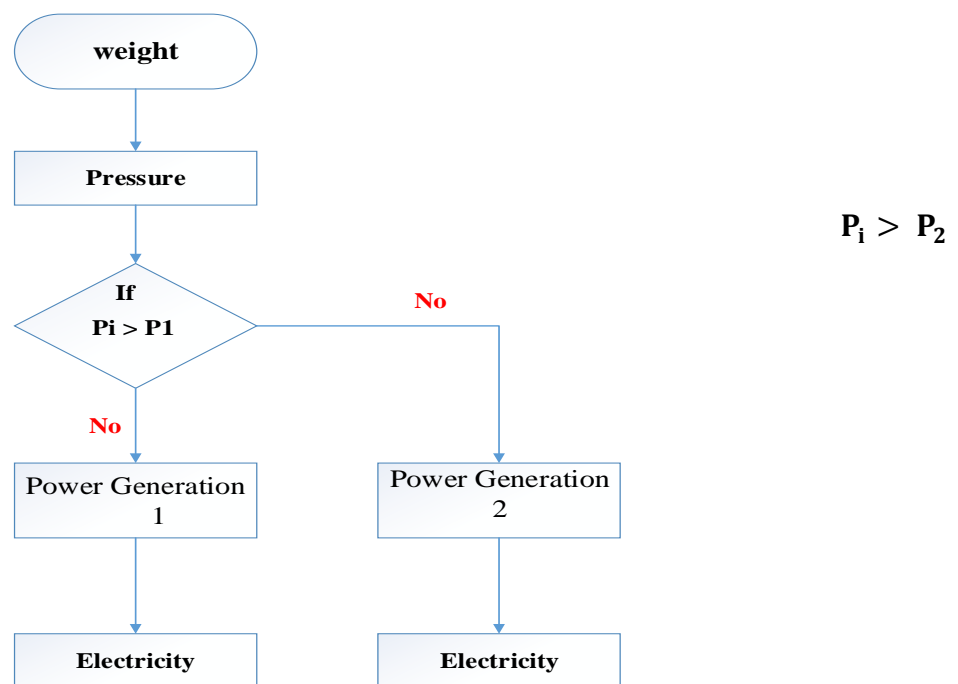


Figure 3-1 power generation at  $P_i > P_1$

If the load applying over the fluid by considering the weight of the piston1 and the weight of the dome is between 2000Kg to 3000Kg the pressure developed inside the cylinder ( $P_i$ ) is between  $P_1$  and  $P_2$  only power generatin 1 generats electricity.

## Electricity Generation from Hydraulic System Speed Breaker

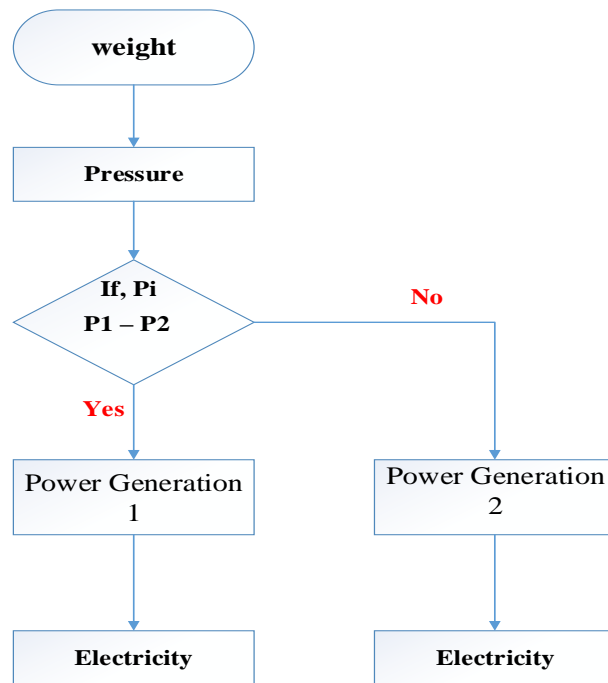


Figure 3-2 power generation at  $P_i$  is between  $P_1 - P_2$

If the load applying over the fluid by considering the weight of the piston1 and the weight of the dome is greater than 3000Kg or the pressure developed inside the cylinder ( $P_i$ ) is greater than minimum working pressure of power generation 2 ( $P_2$ ) both power generation 1 and power generation 2 will generate electricity.

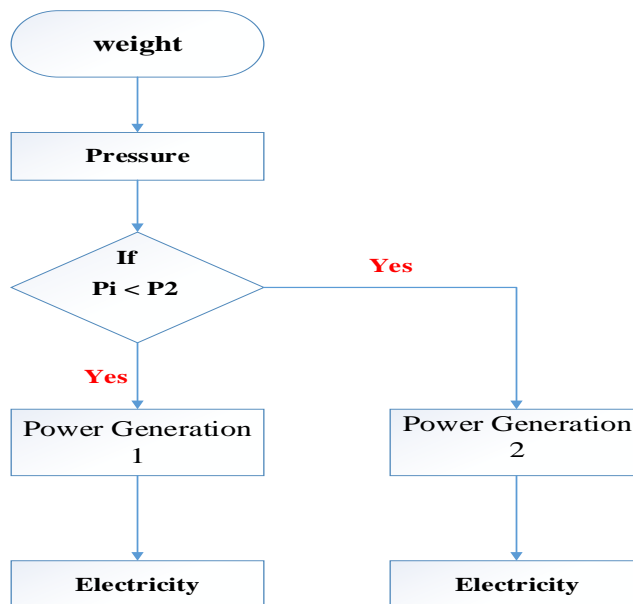


Figure 3-3 power generation at  $P_i < P_1$

### 3.2. Technical design

In this section, the minimum and maximum pressure developed inside the cylinder due to the load of the vehicle by considering the limitation of vehicle weight was calculated. In addition, the equations are developed to design the components of the model so it is possible to calculate the dimension/size by considering the properties of material selected and the pressure inside the cylinder.

#### 3.2.1. Material selection

The material used for this prototype should have to be corrosion resistance, wear resistance, low cost, lightweight and machinability because it should be able to perform its primary function effectively and strong enough to withstand the pressure in the system. The most suitable material selected for springs are those which can store the maximum amount of work or energy with small wire diameter high strength in a given weight or volume of spring and material without permanent deformation. The materials used for springs should have a high elastic limit as well as high deflection value. In this thesis, springs are used to store or absorb energy when the vehicle exerts force on the hydraulic system speed breaker and to restore it when the vehicle passes to provide flexibility. According to the function compression helical springs are used for this new prototype and most commonly used materials are music wire, chrome vanadium, chrome Silicon, 316 Stainless Steel, 302 Stainless Steel and 17-7 Stainless Steel. 316 Stainless steel is widely used alloy spring materials with high corrosion resistance, wear resistance, lightweight, have better operating temperature and easy for machinability.[33] Therefore, in this prototype, seven compression springs are used to restore the speed breaker and 316 stainless steel material is selected for those springs. During selecting a material for a piston, it should be taken into consideration that the strength of the material to withstand the high pressure, the material that have minimum mass to minimize the inertia forces, the material that gives a greater clearance between the piston and the cylinder wall and the material used to provide high speed reciprocation without noise. Most commonly used materials for pistons are cast iron, aluminum alloy, cast steel. Aluminum alloy pistons are used for highly rated at higher piston speeds and used to provide great clearance between the piston and the cylinder wall and also it is about three times lighter than the cast iron with high strength.[34] In this model two pistons are used the material aluminum alloy is selected to provide a better efficiency of the system due to minimizing the inertia force and reducing the friction loss. Stainless is one of the most widely used cylinder material because it is high resistant to

## Electricity Generation from Hydraulic System Speed Breaker

corrosion, high tensile strength and easily available. Due to excellent corrosion resistance and high strength properties stainless steel is selected to manufacture the cylinders. During the manufacturing the prototype for the new prototype the materials are selected by considering the easily availability of the material, suitable of the material for working condition in experimental testing and the cost.

### 3.2.2. Design of the cylinder

According to Bernoulli's principle, Pascal's principle by understanding the fluid behavior and the prototype target two cylinder (the upper narrow cylinder and the lower wider cylinder in figure 3-4) recommended for increasing pinion torque. So in this case the hydraulic fluid is needed for the purpose of force multiplication. hydraulic systems (oil inside the cylinder) used to multiply force and in order to have smooth linear motion. However, piston 1 is smaller than piston 2. Assume that the area of the input piston 1 is half of piston 2. The pressure inside the cylinder due to the weight of the vehicle times the area of the piston 1. This pressure acts on all parts of the fluid container, including the bottom of output piston 2; therefore, the downward force on output piston 2 is twice of the weight of the vehicle due to the area difference. In this case, the original force has multiplied while using the same pressure in the fluid as before. In any system with these dimensions, the ratio of output force to input force is always 2 to 1 regardless of the applied force. However, in this model two fluid-filled cylinders connected together in order to multiply the weight of the vehicle pass over the speed breaker. A downward force  $F_1$  on the upper cylinder creates a pressure that is transmitted undiminished to all parts of the enclosed fluid. This results in downward force  $F_2$  is larger than  $F_1$  because the lower piston has a larger area. One of the most important technological applications of Pascal's principle is found in a hydraulic system, which is an enclosed fluid system used to exert forces.

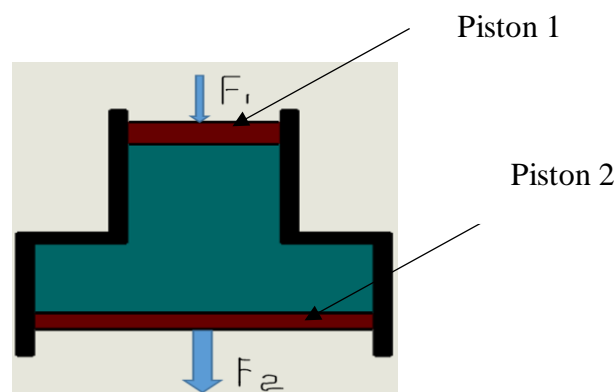


Figure 3-4 proposed hydraulic cylinder

## Electricity Generation from Hydraulic System Speed Breaker

According to Pascal's principle, pressure is transmitted undiminished throughout the fluid and to all walls of the container. The weight of the axle pushing the speed breaker down and acts like  $F_1$ .

Pressure developed inside the two cylinder is force-applied perpendicular to the surface of upper piston due to the weight of the vehicle per unit area over which that force is distributed. Defined as force per unit area; it has the unit of newton's per square meter ( $\text{N}/\text{m}^2$ ), which is called a Pascal (Pa).

$$1 \text{ Pa} = 1 \text{ N}/\text{m}^2$$

Pressure inside the cylinder due to the weight defined as

$$P = \frac{F_1}{A_1} \quad \text{eq}(3.1)$$

Where:  $A_1$  area of the upper piston head

$$F_1 = W = mg$$

However, force acting over the upper piston head is the weight of the axle multiplying by the gravity.

### Area of the cylinder

Internal diameter of the two cylinder assumed by the minimum width of the road. In Ethiopia constricted urban conditions on low speed-roadways, lane widths of 3.0 meters should be the minimum adopted.

### *Assumption*

- ✓ Internal diameter of the upper cylinder  $D_1$  is 1.5 meter
- ✓ Internal diameter of the of the upper cylinder is half of the internal diameter of the lower cylinder
- ✓ The upper piston moves down 14 cm distance and the lower piston will move 6cm due to the area difference of the cylinder.

$$D_2 = 2D_1$$

$$D_2 = 2 \times 1.5$$

## Electricity Generation from Hydraulic System Speed Breaker

$$D_2 = 3 \text{ meter}$$

✓ Area of the upper cylinder is

$$A_1 = (\pi/4) \times D_1^2$$

$$A_1 = (\pi/4) \times 1.5^2$$

$$A_1 = 1.767 \text{ m}^2$$

✓ Area of the lower cylinder

$$A_2 = (\pi/4) \times D_2^2$$

$$A_2 = (\pi/4) \times 3^2$$

$$A_2 = 7.06 \text{ m}^2$$

The out force ( $F_2$ ) from the hydraulic system speed breaker is defined as pressure times the area of the lower piston head.

$$F_2 = P \times A_2$$

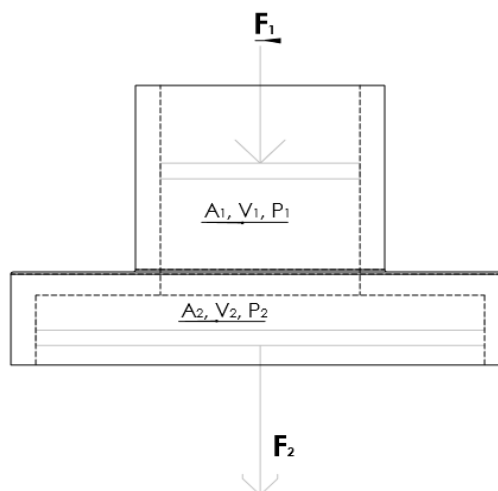


Figure 3- 5 direction of the force and the speed inside the cylinder

The speed of the piston head inside the upper cylinder or the upper piston is twice of the lower cylinder or lower piston

$$V_1 = 2V_2$$

Pressure developed inside the upper cylinder and the lower cylinder due to the weight of the vehicle is the same

$$P_1 = P_2$$

## Electricity Generation from Hydraulic System Speed Breaker

### Pressure developed according to the limitation of weight of the vehicle

Weight rating limits are usually set as a guideline by the designer, protecting the equipment and simplifying the design of larger systems, by providing a level of operation under which the equipment will not be damaged while allowing for a certain safety margin.

However, according to the International Transport Forum August 3, 2015 the maximum weight of the drive axle is 11.5 ton [28][29]. Therefore, in this case the maximum permissible weight of the axle for electricity generation applying over the hydraulic system speed breaker is 11.5 ton or 11500 Kg. In addition, the minimum permissible weight of the axle is assumed 0.5 ton or 500Kg.

Therefore, the maximum and minimum pressure developed inside the two cylinder is calculated

$$P_{\max} = \frac{M_{\max} \times \text{gravity}}{\text{Area of the upper piston}} = \frac{11500 \times 9.81}{1.767} = 63845 \text{ N/m}^2 = 63845 \text{ pa}$$

$$P_{\min} = \frac{M_{\min} \times \text{gravity}}{\text{Area of the upper piston}} = \frac{1000 \times 9.81}{1.767} = 5551.78 \text{ N/m}^2 = 5551.78 \text{ pa}$$

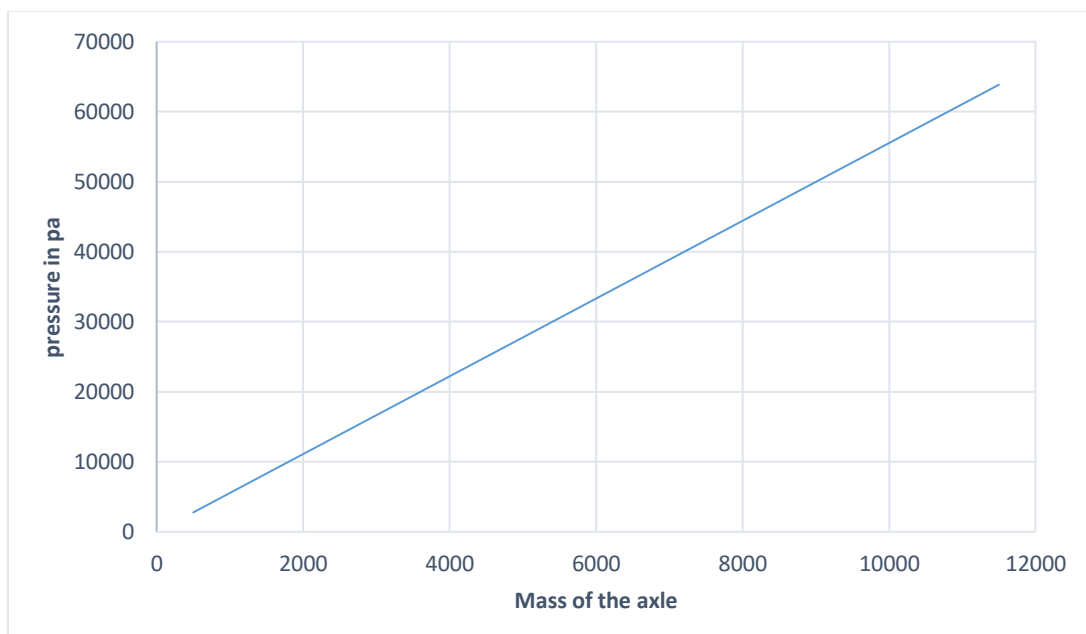


Figure 3- 6 pressure versus mass of the axle

## Electricity Generation from Hydraulic System Speed Breaker

### Cylinder wall thickness

If we apply internal pressure, the cylinder subjected to

- Circumferential stress, which is tensile stress applying in a direction of tangential to the circumference.

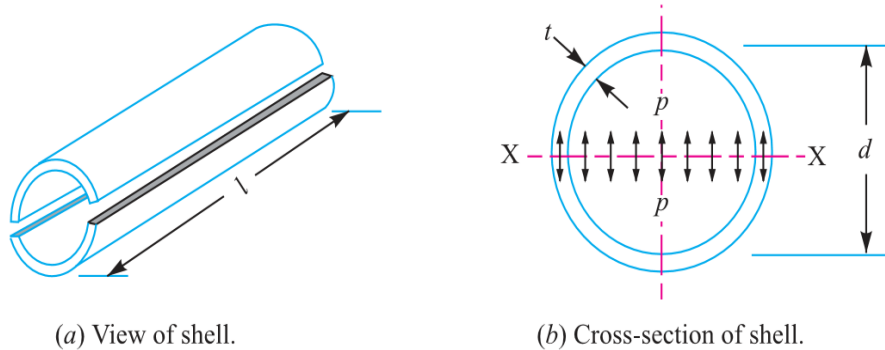


Figure 3-7 tensile stress on longitudinal section. (Machine-Design-R-S-Kurmi)

Force acting on the longitudinal section

$$F = P \times A$$

where  $A$  is projected area  $= d \times t$

$$F = P \times d \times t \quad eq(3.2)$$

Total resisting force acting on the cylinder wall

$$F_r = \sigma_t \times 2t \times l \quad eq(3.3)$$

where  $\sigma_t$  circumferential stress for the material of cylinder wall

therefore from those equation

$$P \times d \times t = \sigma_t \times 2t \times l$$

$$t = \frac{P \times d}{2 \sigma_t} \quad eq(3.4)$$

## Electricity Generation from Hydraulic System Speed Breaker

- b) Longitudinal stress, which is tensile stress applying in the direction of the axis

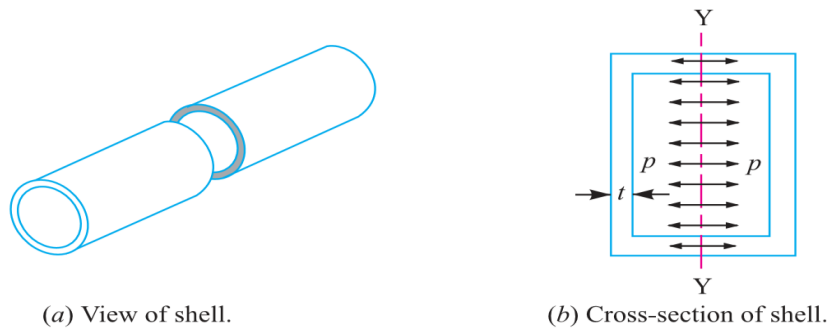


Figure 3-8 tensile stress acting on the circumferential axis. (Machine-Design-R-S-Kurmi)

Force acting on the circumferential section

$$F = P \times \frac{\pi d^2}{4}$$

In addition, the resistance force

$$F_r = \sigma_t \times \pi d \times t \quad eq(3.5)$$

From *eq(4.1)* and *eq(4.5)*

$$\sigma_t \times \pi d \times t = P \times \frac{\pi d^2}{4}$$

$$t = \frac{p \times d}{4\sigma_t} \quad eq(3.6)$$

However, as we see in the above two equations the thickness that we can found from the equation of circumferential stress is twice of the thickness that we can calculate from the equation of longitudinal stress. So simply we can use the equation of circumferential stress in order to calculate the wall thickness[34].

### Thickness of the piston head ( $T_h$ )

According to the Grashoff's formula thickness of the piston is given by

$$T_h = \sqrt{\frac{3p \cdot D^2}{16 \sigma_t}} \quad eq(3.7)$$

### Length of the hydraulic cylinder

Length of the hydraulic cylinder assumed by considering height of the speed breaker that traveled downward due to the weight of the vehicle over the hydraulic system speed breaker and the thickness of the piston head. Also in the assumption the length of the cylinder 2 / lower cylinder, the pressure-setting valve will also under consideration.

### 3.2.3. Spring design

Spring is a mechanical device, which is design to store energy when load apply and to return an equivalent amount of energy when it released.

To design a new spring we should have to involve following considerations:

- ✓ Values of the working weight and maximum deflections.
- ✓ The accuracy and reliability needed.
- ✓ Environmental conditions such as temperature, presence of a corrosive atmosphere.
- ✓ Cost and qualities needed

The designers should have to use the above factors to select a material and specify suitable dimensions of the wire such as wire diameter, number of turns, free length and solid length of the spring working load the maximum deflection needed. In this model helical spring selected according to the arrangement which is made of circular cross-section. Most commonly used cross-section is circular. Helical spring material should have high ultimate strength and good yield point in order to provide good energy storage when force act on it[34].

✚ Compression spring variation of length due to applying load

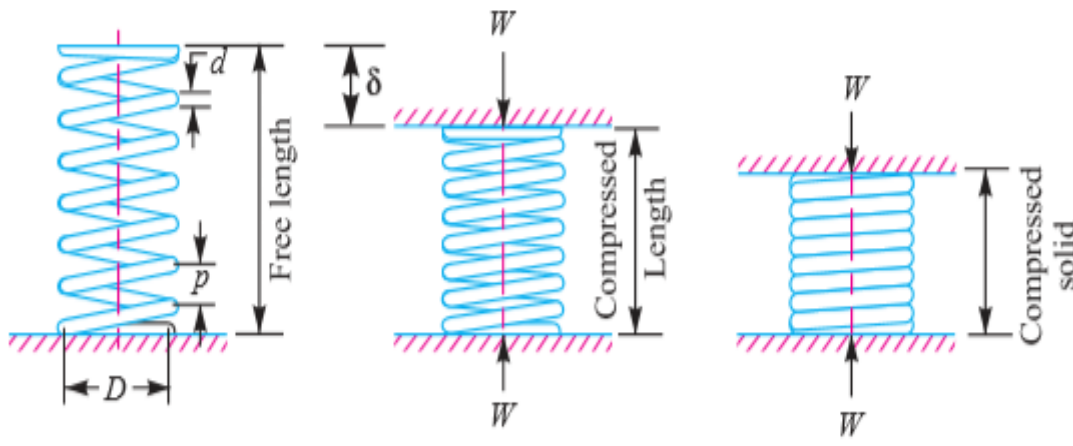


Figure 3-9 Compression spring nomenclature. Machine-Design-R-S-Kurmi [34]

Solid length of the helical spring;

$$L_s = n' \times d \quad eq(3.8)$$

Free length of the spring;

$$\begin{aligned} L_f &= \text{Solid length} + \text{Maximum compression} + \text{*Clearance between adjacent} \\ &\quad \text{coils (or clash allowance)} \\ &= n' \times d + \delta_{\max} + 0.15 \delta_{\max} \end{aligned} \quad eq(3.9)$$

The following relation can also use to find the free length of the helical spring,

$$L_f = n' \times d + \delta_{\max} + (n' - 1) \times 1 \text{ mm} \quad eq(3.10)$$

In this expression, the clearance between the two adjacent coils can take as 1 mm.

Spring index,

$$C = D / d \quad eq(3.11)$$

Spring rate. (Or stiffness or spring constant)

$$k = W / \delta \quad eq(3.12)$$

Pitch. Pitch of the spring can defined as the axial distance of the coil between adjacent coils in uncompressed state. Mathematically,

Pitch of the spring,

$$p = \frac{\text{free length}}{n' - 1} \quad eq(3.13)$$

## Electricity Generation from Hydraulic System Speed Breaker

The pitch of the spring may also be obtained by using the following relation

$$p = \frac{L_f - L_s}{n'} + d \quad eq(3.14)$$

Stresses in Helical Springs;

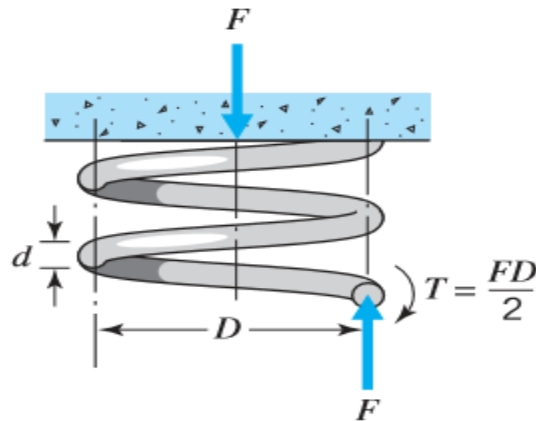


Figure 3-10 wire subjected to torsional shear and a direct shear Shigley's Mechanical Engineering Design [35]

From the above free body diagram the torque T acting on the spring as given below

$$T = F \times \frac{D}{2} \quad eq(3.15)$$

A little consideration will show that part of the spring, as shown in Figure 4.2 the action of two forces and the twisting moment. We know that the twisting moment,

$$T = \frac{\pi}{16} \times \tau \times d^3 \quad eq(3.16)$$

By substitute eq (3.15) to eq (3.16)

$$F \times \frac{D}{2} = \frac{\pi}{16} \times \tau \times d^3$$

$$\tau_t = \frac{8 FD}{\pi d^3} \quad eq(3.17)$$

Direct shear stress due to the load W, applied over the spring is

$$\tau_d = \frac{\text{Load}}{\text{Cross-sectional area of the wire}}$$

## Electricity Generation from Hydraulic System Speed Breaker

✓ Cross – sectional area of the wire

$$A = \frac{\pi d^2}{4}$$

By substituting the above equation in to direct shear stress formula

$$\tau_d = \frac{F}{\frac{\pi d^2}{4}}$$

$$\tau_d = \frac{4F}{\pi d^2} \quad eq(3.18)$$

The resultant shear stress of the spring is torsional plus or minus of the direct shear stress and the maximum shear stress induced in the internal edge of the spring.

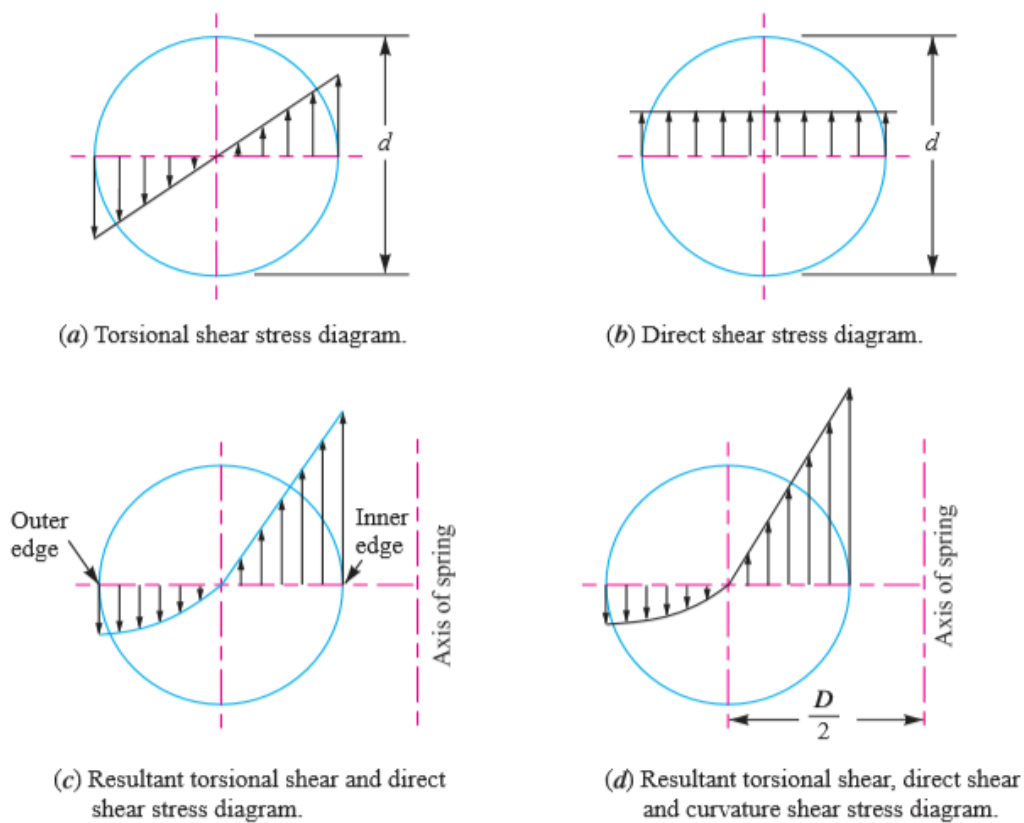


Figure 3-11 Superposition of stresses in a helical spring Machine-Design-R-S-Kurmi [34]

Therefore, the resultant shear stress on the helical spring when the weight of the vehicle applying over the speed breaker is calculated

$$\tau = \tau_t \pm \tau_d \quad eq(3.19)$$

## Electricity Generation from Hydraulic System Speed Breaker

The positive sign used for the internal surface of the spring and negative sign used for the outer surface of the spring. Since the stress is maximum at the internal surface of the spring, therefore

$$\tau = \frac{8FD}{\pi d^3} + \frac{4F}{\pi d^2} = \frac{8FD}{\pi d^3} \left( 1 + \frac{d}{2D} \right)$$

Substitute spring index  $C = \frac{D}{d}$

$$= \frac{8FD}{\pi d^3} \left( 1 + \frac{1}{2C} \right)$$

Therefore the maximum shear stress occurring on the spring is

$$\tau = k_s \times \frac{8FD}{\pi d^3} \quad eq(3.20)$$

$$\text{Where } k_s = \text{Shear stress factor} = \left( 1 + \frac{1}{2C} \right)$$

To include the curvature effect on the spring the factor  $k_s$  needs to be modified because the curvature of the spring can cause to increase the stress in the inside surface of the spring but decreases slightly on the outside surface of the spring. In static load: these stresses may normally be neglected because it can be relieved by local yielding with first application of a force[35].

In order to consider the effect of both direct shear and curvature of the spring a Wahl's shear factor  $k_w$  introduced. the earlier equation *eq(3.20)* for maximum shear stress in the spring wire is modified as,

$$\tau = k_w \times \frac{8FD}{\pi d^3} \quad eq(3.21)$$

Where,  $k_w$  is Wahl correction factor, is both curvature effect and shear stress correction factor;

$$k_w = \frac{4C-1}{4C-4} + \frac{0.615}{C}$$

Deflection of helical spring is

$$\delta = \theta \times \frac{D}{2} \quad eq(3.22)$$

## Electricity Generation from Hydraulic System Speed Breaker

The angular deflection of the spring when acted upon by the torque

$$\theta = \frac{16 F D^2 n}{d^4 G} \quad eq(3.23)$$

Therefore, by substituting eq (3.23) in to eq(3.22) we get the following equation

$$\delta = \frac{8 F D^3 n}{d^4 G}$$

*Substitute C = D/d*

$$\delta = \frac{8 F C^3 n}{d G} \quad eq(3.24)$$

Total active length of the wire,

$$L = \text{Length of one coil} \times \text{No. of active coils} = \pi D \times n$$

Stiffness of the spring; it is also known as spring rate (also called spring constant with units of Newton's per millimeter) commonly designated as k, is

$$K = \frac{F}{\delta} = \frac{Gd}{8C^3 n} \quad eq(3.25)$$

### 3.2.4. Gear design

Here in this case the main objective of the gear is to transfer the motion. If the pinion is the driver, it results in step down drive it means the output speed is decreases and the torque increases on the other hand; when the gear is the driver it results in step up drive the output speed increases or torque decreases[26].

#### Spur gear

In this case, spur gear is selected because it is simple in construction, easy to manufacture, less cost, it have also highest efficiency and excellent precision rating. Teeth's are parallel to the axis of the rotation so it is used to transmit power between two parallel shafts. Spur gears are selected also because of it is used in high speed and high load application in all types of trains and a wide range of velocity ratios[36].

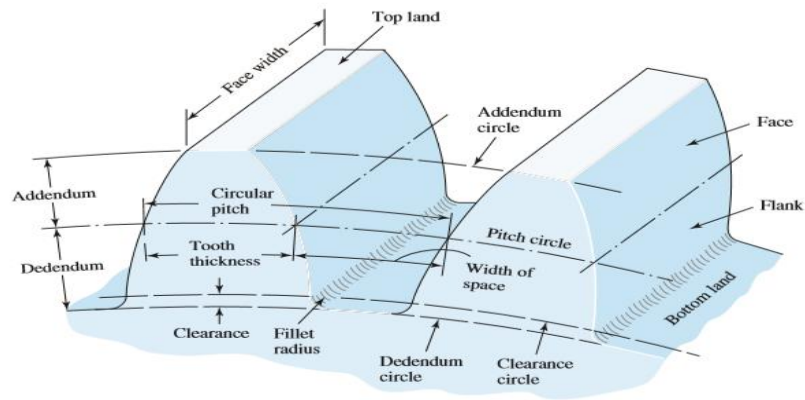


Figure 3-12 Nomenclature of spur-gear teeth, shigley's mechanical engineering design[35]

Where radius of the gear is  $r$  Circumference of the pitch circle is

$$C = 2\pi r \quad eq(3.26)$$

Number of teeth if the pitch of the gear used is  $p$

$$n = \frac{2\pi r}{P} \quad eq(3.27)$$

**Circular pitch ( $p$ );** as shown in the figure 4.4, it is the distance between corresponding points on adjacent teeth measured along the pitch circle

$$P_c = \frac{\pi d}{N} \quad eq(3.28)$$

**Diametral pitch:** is the number of teeth per inch of pitch diameter.

$$P_d = \frac{N}{d} \quad eq(3.29)$$

Pitch diameters of the pinion and gear

$$d_p = \frac{N_p}{P}$$

$$d_g = \frac{N_g}{P}$$

Where  $d_1$  and  $d_2$  are the diameters of the two meshing gears having the teeth  $N_1$  and  $N_2$  respectively; then for them to mesh correctly

$$P_c = \frac{\pi d_1}{N_1} = \frac{\pi d_2}{N_2} \quad \text{OR} \quad \frac{d_1}{d_2} = \frac{N_1}{N_2}$$

**Module.** It is the ratio of the pitch circle diameter in to the number of teeth.

Mathematically it is

## Electricity Generation from Hydraulic System Speed Breaker

$$m = \frac{d}{N} \quad eq(3.30)$$

**Velocity ratio** the ratio of rotational speed of the input gear to that of the output gear

$$V_r = \frac{N_g}{N_p} = \frac{d_g}{d_p}$$

There are different systems of gear teeth used in different industries. But commonly used in practice are

1.  $14\frac{1}{2}^\circ$  composite system
2.  $14\frac{1}{2}^\circ$  full depth involute system
3.  $20^\circ$  full depth involute system
4.  $20^\circ$  sub involute system

Table 3-1 Standard proportions in module, source r.s. khurmi j.k. gupta [34]

No.	Particulars	$14\frac{1}{2}^\circ$ composite and full depth involute system	$20^\circ$ full depth involute system	$20^\circ$ sub involute system
1	Addendum	1m	1m	0.8m
2	Dedendum	1.25m	1.25m	1m
3	Working depth	2m	2m	1.60m
4	Minimum total	2.25m	2.25m	1.80m
5	depth	1.5708m	1.5708m	1.5708m
6	Tooth thickness	0.25m	0.25m	0.2m
7	Minimum clearance	0.4m	0.4m	0.4m
	Fillet radius at root			

To calculate the number of teeth on the pinion

$$N_p = \frac{2 A_w}{G_R * \sqrt{1 + \frac{1}{G} \left( \frac{1}{G} + 2 \right) \sin^2 \phi} - 1} \quad eq(3.31)$$

### Strength of Gear Teeth

The tangential component  $W_t$  apply a bending stress, which causes to break the teeth the radial component  $W_r$  apply a compressive stress of its effect on the teeth can be neglected.

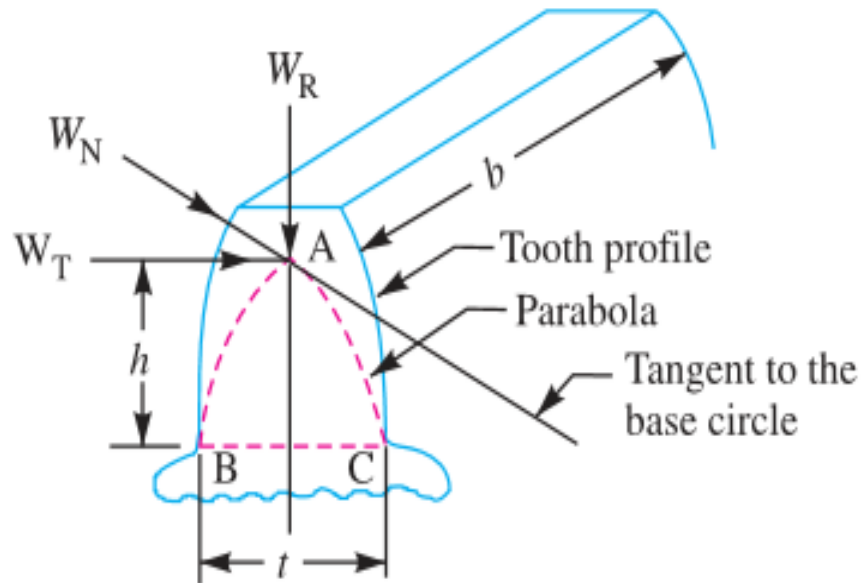


Figure 3-13 tooth of a gear, r.s. khurmi j.k. gupta [34]

The permissible working stress ( $\sigma_w$ ) at the section BC is given as the following equation

$$\sigma_w = \frac{M \cdot y}{I} \quad eq(3.32)$$

To calculate the maximum bending moment ( $M$ ) at the section of BC =  $W_t \times h$  and also we can calculate the half thickness of the teeth ( $y$ ) at the section of BC which is  $t/2$ .

However, moment of inertia ( $I$ ) at the center line of the tooth is given

$$I = \frac{b \cdot t^3}{12} \quad eq(3.33)$$

So by substituting the above formula

$$\sigma_w = \frac{(W_t \times h) \cdot t/2}{\frac{b \cdot t^3}{12}} = \frac{(W_t \times h) \times 6}{b \cdot t^2}$$

$$W_t = \sigma_w \times b \times t^2 / 6h \quad eq(3.34)$$

## Electricity Generation from Hydraulic System Speed Breaker

However, we can also obtain Tangential tooth load ( $W_t$ ) from the power transmitted and the pitch line velocity by using the following relation

$$W_t = \frac{P_o}{v} \times C_s \quad eq(3.35)$$

In this case  $P_o$  is power transmitted in watts,  $C_s$  service factor and  $v$  pitch line velocity we may also calculate by the following relation

$$v = \frac{\pi d N}{60} \quad eq(3.36)$$

$N$  is speed in R.P.M and  $d$  is pitch circle diameter

Table 3-2 Values of service factor, source r.s. khurmi j.k. gupta [34]

Type of load	Intermittent or 3 hours per day	8 – 10 hours Per day	Continuous 24 hours Per day
Steady	0.8	1.00	1.25
Light shock	1.00	1.25	1.54
Medium shock	1.25	1.54	1.80
Heavy shock	1.54	1.80	2.00

### 3.2.5. Design of gear trains

The torque produced on the pinion due to the load of the vehicle is high so a pair of gear cannot meet the requirement of transmission. In the case spur gears are used the angles between driving and driven shaft is 0 degree or the shafts are parallel spur gears are the most commonly used and the simplest one[35].

## Electricity Generation from Hydraulic System Speed Breaker

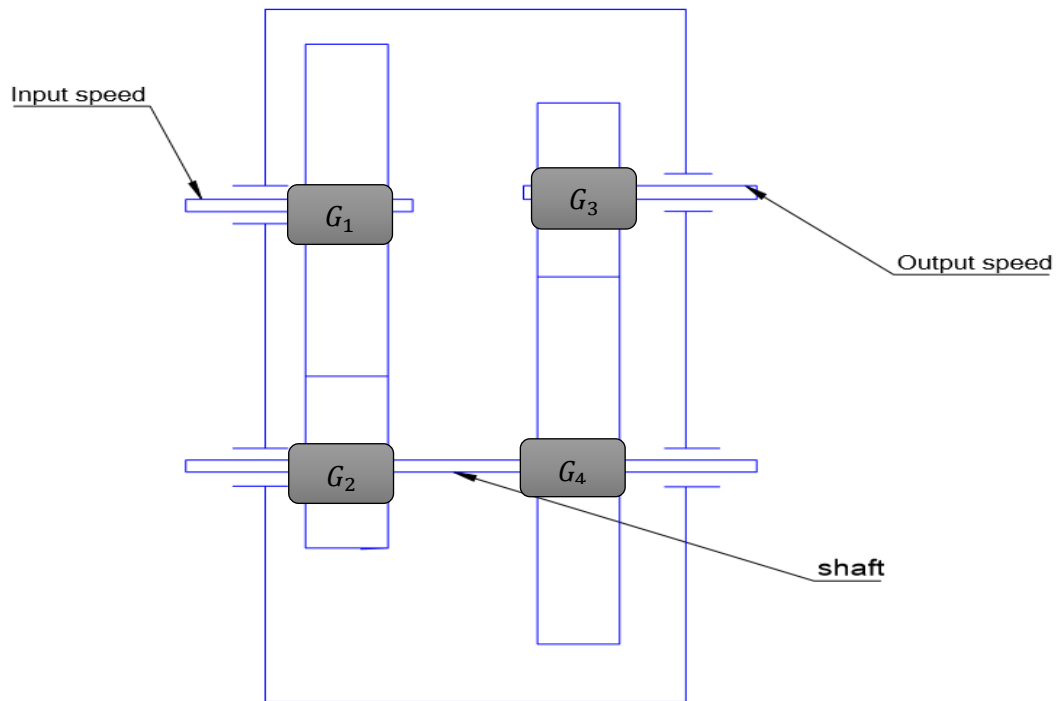


Figure 3-14 Layout of Two-Stage Gearbox

The rotational motion is characterized by the angle of velocity ( $\omega$ ) which is defined as in angular displacement ( $\theta$ ) divided by in time (t).

$$\omega = \frac{\theta}{t} \quad eq(3.37)$$

In addition, the angular velocity is also known as rotational speed it can be measured in numbers revolutions per minute (rpm) or per second (rps).

$$\omega = \frac{2\pi N}{60}$$

The power transmitted by the rotational motion of the gear is given

$$P = T \times \omega \quad eq(3.38)$$

The amount of torque applied on the gear is calculated, the radius of the wheel multiply by the force applied tangentially.

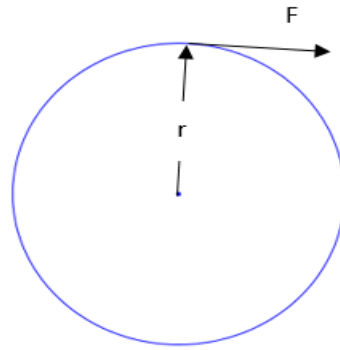


Figure 3-15 tangential force acting on the gear

In order to produce torque, the force will act at some distance from the axis as shown in the above diagram, the circle represents a wheel of radius the dot in the center of the gear or shaft; and the force will applied tangentially.

$$T = F \times r \quad eq(3.39)$$

Therefore the power transmitted by the gear is

$$P = F \times r \times \omega$$

$$\text{Or } P = \frac{2\pi N}{60} \times T$$

If we consider the two gears in a mesh, Gear 1 is the driver it turning counterclockwise at angular velocity  $\omega_1$  and has  $Z_1$  teeth. Gear 2 is driven is turning clockwise with angular velocity  $\omega_2$  and has  $Z_2$  teeth.

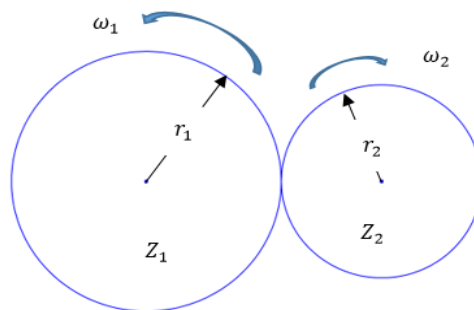


Figure 3-16 Two Gears in a mesh

Where the gear is rotating the power transmitted is

$$P_{in} = T_1 \times \omega_1$$

$$P_{out} = T_2 \times \omega_2$$

## Electricity Generation from Hydraulic System Speed Breaker

If the friction produced between the gears is not considered the input power and the out put power is equele

$$P_{in} = P_{out}$$

Therefore;

$$T_1 \times \omega_1 = T_2 \times \omega_2$$

$$\frac{T_2}{T_1} = \frac{\omega_1}{\omega_2}$$

However, in this case two stage gear train is used as we discuse in the above the layout is composed of the gear pairs 1-2, 2-3 and 3-4. If we consider gear 1 the first gear (driver) and gear 4 is the last gear(driven). So in this case the tranmission ratio(i) of all gear train is

$$i_{14} = \frac{\omega_1}{\omega_4} \quad eq(3.40)$$

The transmission ratio of gear train for each meshing gear is

$$i_{12} = \frac{\omega_1}{\omega_2} = \frac{Z_2}{Z_1} \quad \text{where } \omega_1 = \frac{2\pi N_1}{60}$$
$$= \frac{N_1}{N_2} = \frac{Z_2}{Z_1} ,$$

$$i_{23} = \frac{N_2}{N_3} = \frac{Z_3}{Z_2}$$

$$\text{and } i_{34} = \frac{N_3}{N_4} = \frac{Z_4}{Z_3}$$

### 3.2.6. Design of Shaft

In designing the shaft understanding the strength of the shaft is basic and to know that we have to consider the twisting moment and bending moment applying on it. In this model, there are two shafts but the main shaft used to transmit from the pinion to the main gear 1.

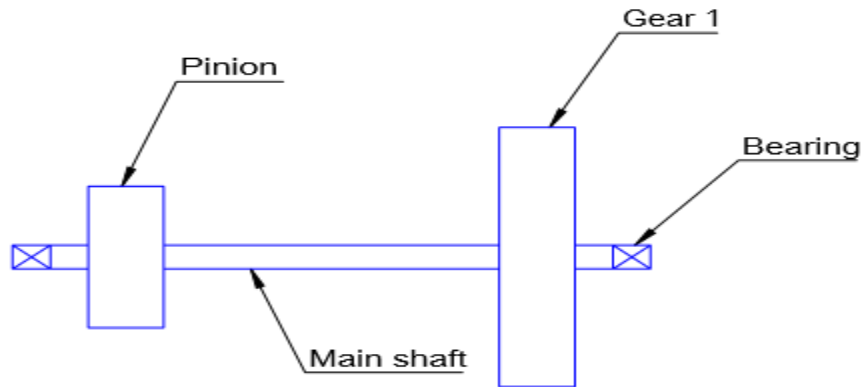


Figure 3-17 main shaft and the gear

When the shaft subjected to the twisting moment (T)

$$T = \frac{\pi}{16} \times \tau \left[ \frac{(d_o)^4 - (d_i)^4}{d_o} \right] \quad \text{for the hollow shaft} \quad \text{eq(3.41)}$$

$$T = \frac{\pi}{16} \times \tau \times d^3 \quad \text{for the solid shaft} \quad \text{eq(3.42)}$$

$$\text{Therefore } d^3 = \frac{16 T}{\pi \tau}$$

If we know the speed of the shaft (N) and the power, transmitted (P) the twisting moment may obtained by using relation

$$P = \frac{2 \pi N \times T}{60} \quad \text{eq(3.43)}$$

$$\text{Or } T = \frac{P \times 60}{2 \pi N}$$

**When the shaft subjected to the bending moment (M)**

$$M = \frac{\pi}{32} \times \sigma_b \times d^3 \quad \dots \quad \text{For solid shaft} \quad \text{eq(3.44)}$$

$$M = \frac{\pi}{32} \times \sigma_b \times (d_o)^3 (1 - k^4) \quad \dots \quad \text{For hollow} \quad \text{eq(3.45)}$$

$$\text{Where } k = d_i/d_o$$

**If the shaft subjected to the combined bending and twisting moment**

Equivalent twisting moment ( $T_e$ ) according to maximum shear stress theory, for solid shaft may obtained from the following

## Electricity Generation from Hydraulic System Speed Breaker

$$T_e = \sqrt{M^2 + T^2} = \frac{\pi}{16} \times \tau \times d^3 \quad eq(3.46)$$

Equivalent bending moment ( $M_e$ ) according to maximum shear stress theory for solid shaft

$$M_e = \frac{1}{2} [ M + \sqrt{M^2 + T^2} ] = \frac{\pi}{32} \times \sigma_b \times d^3 \quad eq(3.47)$$

From the above two equations which is easy to evaluate the shaft diameter  $d$ . then we have to take the larger diameter of the shaft from the those two result. However for the hollow shaft the equivalent twisting moment and the equivalent bending moments are obtained from the following equations;

$$T_e = \sqrt{M^2 + T^2} = \frac{\pi}{16} \times \tau (d_o)^3 (1 - k^4) \quad eq(3.48)$$

$$M_e = \frac{1}{2} [ M + \sqrt{M^2 + T^2} ] = \frac{\pi}{32} \times \sigma_b (d_o)^3 (1 - k^4) \quad eq(3.49)$$

$$\text{Where } k = d_i/d_o$$

The internal and the outer diameter of the shaft may be obtained by the above theories and the larger of the two result is adopted.

### 3.3. CAD Modeling

The proposed prototype has been designed using solid work software and the simulation analyzed using ANSYS 19.2 (workbench). 3D of the new prototype and the arrangement of the power generation is designed using solid work. The model geometry is imported to ANSYS 19.2 (workbench) for the simulation to identify time consumption for the motion of speed breaker in seconds and deflection of the speed breaker in millimeters by applying different pressure on the surface of the piston. The model have two power generation ( $PG_1$  and  $PG_2$ )  $PG_1$  is used to convert 1000 Kg to 2000 Kg weight of the vehicle to electricity and  $PG_2$  is used to convert 2000 Kg to 7000 Kg weight of the vehicle in to electricity. However, the simulation of  $PG_1$  was done by applying pressures on the upper surface of the piston which ranges from 11103.56 to 16655.34  $N/m^2$  and  $PG_2$  was done by applying on the front surface of the piston pressure ranges from 16655.34 to 44414.26  $N/m^2$ .

A lot of researcher study on the mechanisms of electricity generation from speed breaker but the efficiency is still less because they are using one power generation station and it is impossible to have efficient technology due to variation of the vehicle weight and fixed height of the speed breaker. The modification on this thesis is the model have two-power generation here power generation 1 aimed to convert 1000Kg – 3000Kg weight of the vehicle and power generation 2 is to convert 3000Kg – 7000Kg weight of the vehicle to electricity. Hydraulic transmission system is easy to control also it helps in order to have smooth motion it increases the efficiency of the system. Rack and pinion is designed to convert the linear motion to rotational motion and purpose of the gearbox is to maximize the speed of the pinion shaft. In this prototype, two DC generators are used for PG 1 and PG 2 to convert the mechanical energy output from gearbox to electricity.

Main consideration on the design of the prototype is to increase the efficiency and to maximize power production so using hydraulic system speed breaker by replacing the traditional mechanism is for that purpose.

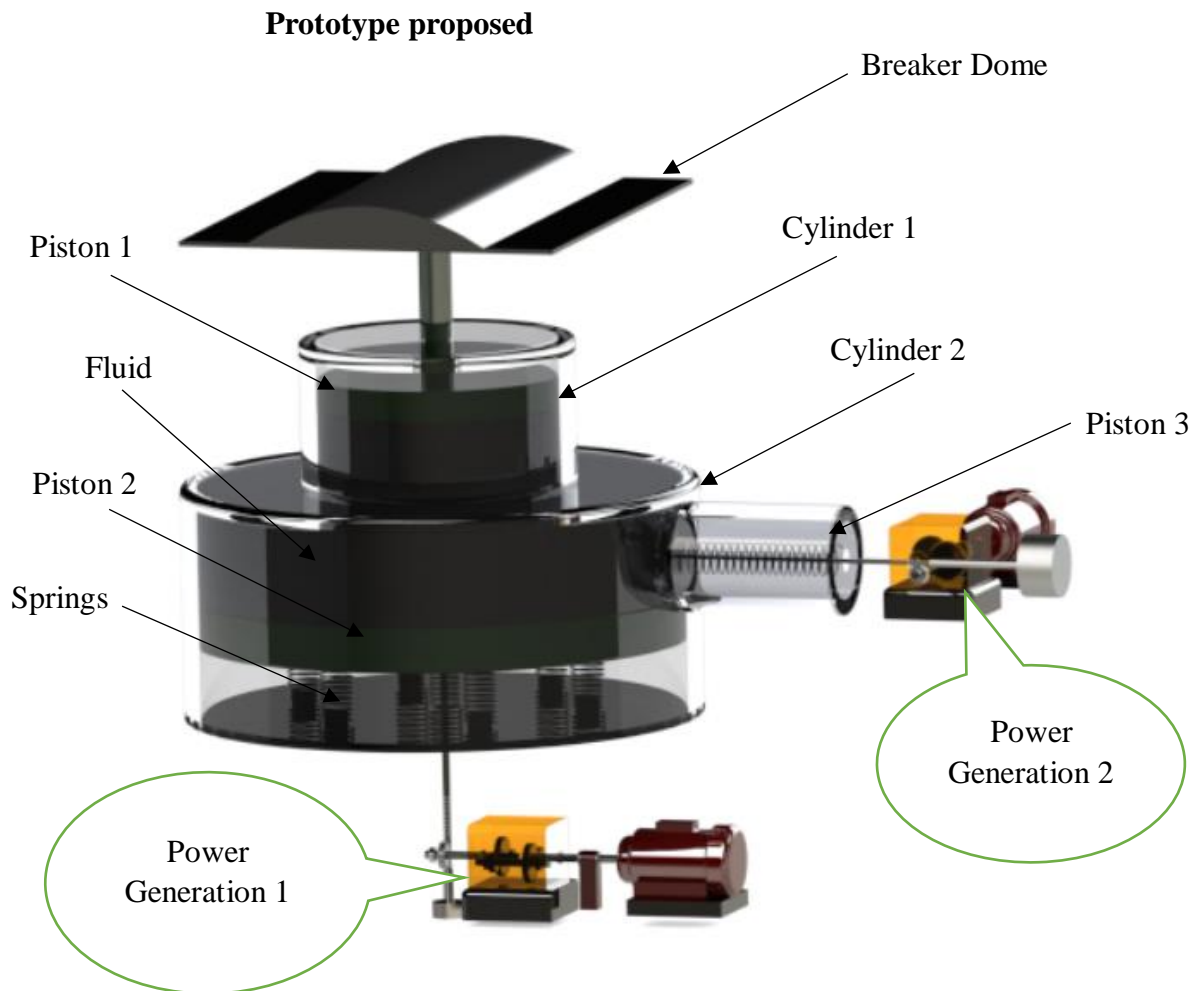


Figure 3-18 3D of the prototype proposed

However, as the prototype arrangement when the vehicle moves over the speed breaker dome it exerts force on it, that force acts on the fluid to produce a pressure inside the cylinder and due to that pressure piston 2, and piston 3 will have a linear motion. The height of the speed breaker assumed 14 cm and the internal diameter of the cylinder 2 is twice of the cylinder 1 so if the piston 1 moves 10 cm the piston 2 will travel 5 cm therefore the remain 4 cm will travel through the piston 3 if more than the allowable pressure develops inside the cylinder. From Bernoulli's principle the prototype have two cylinder (the upper narrow cylinder and the lower wider cylinder) A fluid's speed increases as it travels through narrower spaces and decrease as it travels through wider spaces. Pascal's principle also discusses change in pressure on a fluid is transmit equally to all points in the fluid and the enclosing surface of the container. This is the principle of the hydraulic press. In addition, the static pressure acts at right angles to any surface in contact with the fluid. Moreover, Pascal's principle implies that the total pressure in a fluid is the sum of the pressures from different sources. In this case, hydraulic systems (oil inside the cylinder) used to multiply

## Electricity Generation from Hydraulic System Speed Breaker

force and in order to have smooth linear motion. However, piston 1 is smaller than piston 2 in diameter or assume that the diameter of the input piston 1 is half of piston 2. The pressure inside the cylinder due to the weight of the vehicle times the area of the piston 1. This pressure acts on all parts of the fluid container, including the bottom of output piston 2; therefore, the downward force on output piston 2 is twice of the weight of the vehicle due to the area difference. In this case, the original force has multiplied while using the same pressure in the fluid as before. In any system with these dimensions, the ratio of output force to input force is always 2 to 1 regardless of the applied force.

### 3.3.1. Arrangement of $PG_1$

Rack and pinion is used to convert the resprocating motion of the fluid in to the rotational motion and the force assumed to rotate the pinion is 75KN also the permissible maximum linear displacement of the rack is 50mm. power generation 1 is used only to convert the pressure applying over the upper surface of piston 2 in to electricity. The pressure applying on the upper surface of piston 2 caused to linear motion for the rack and converted to electricity due to the arrangement of power generation. however, the assumption of speed breaker length is 140mm so the diameter of piston 2 is twice of the diameter of piston 1 therefore 100 mm displacement of the piston 1 can cause 50 mm displacement of piston 2.

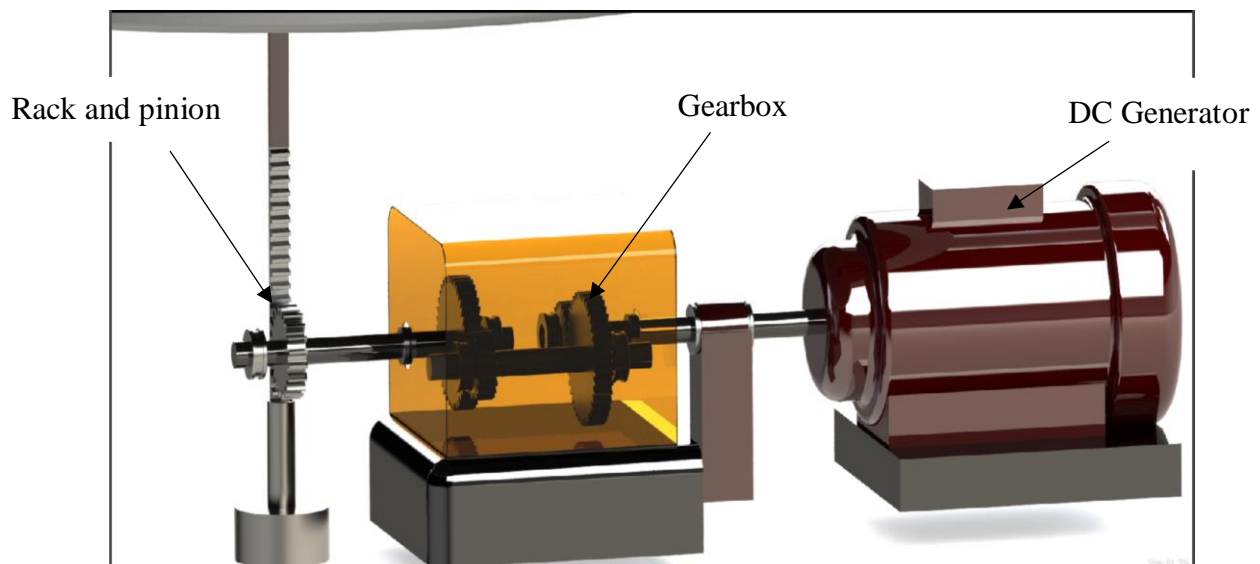


Figure 3- 19 3D of the arrangement  $PG_1$

The gearbox is used to convert the torque produced in the pinion in to high speed and DC generator converts the mechanical speed to electricity. When the pinion shaft starts to rotate the generator starts to generate electricity. The speed which is sufficient to rotate the rotor of the generator is feed to the rotor of the generator.

### 3.3.2. Arrangement of $PG_2$

The arrangement is the same with power generation 1 but in this case, the force used to rotate the pinion is 3 KN. Also the permissible maximum displacement of the rack mechanism is 120 mm. overall the length of the speed breaker is assumed 140 mm and 100 mm length is used for power generation 1 the remain 40 mm is for power generation 2. In the case of power, generation 2 diameter of the piston is very small and 40 mm displacement of the piston 1 can cause 120 mm displacement of piston 3. The Arrangement as shown in the figure below;

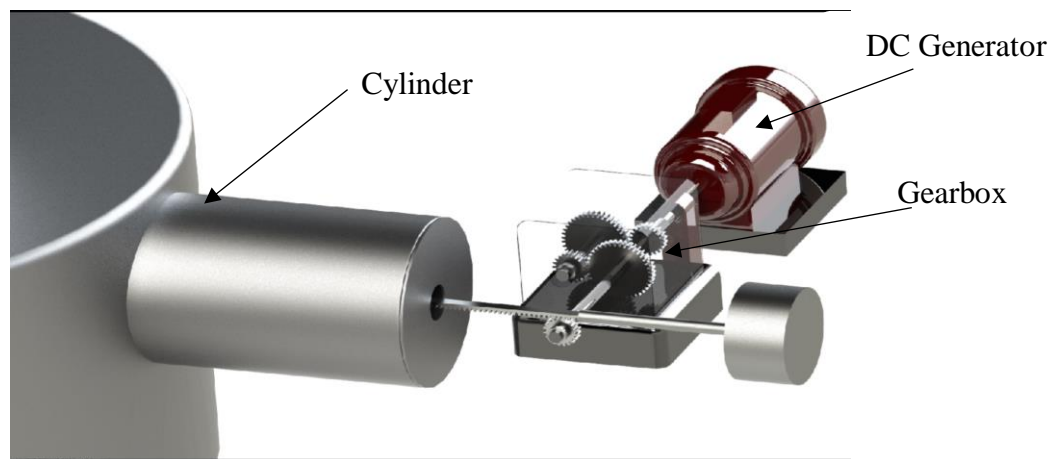


Figure 3-20 3D of the Arrangement  $PG_2$

In order to design the arrangement the dimensions are taken by considering the possible pressure developed inside the cylinder when different weight of the vehicle passes through the speed breaker and the maximum height of the speed breaker. According to the size of the arrangement  $PG_2$  is used generate electricity up to 0.4 KW power.

### 3.4. Displacement of the speed breaker (simulation study)

Spring is flexible which is used to store the energy if force apply on it and exert when the load remove [37] so the main objective of the section is to analyze the displacement of the piston when weight apply over the speed breaker. In this thesis, simulation is done to identify when the vehicle moves over the hydraulic system speed breaker how much length the speed breaker travels downward. The simulation used to determine whether the model is practically work just like the assumption or there is need of improvement or needs change on the design of the model. To analyze the displacement ANSYS 19.2 (workbench) is used.

### 3.4.1. Methods of the simulation

After opening the ANSYS software first step is selecting the material, then second step CAD model is imported and meshed with required size. The spring is fixed with the piston and the fixed supporter if pressure apply over the piston surface the piston moves downward the spring will deflect. In this simulation at one end the the spring is loaded and fixed on the other surface. At the last checking the displacement of the speed breaker by applying different pressure on the surface of the piston. By considering different weight of the vehicle, the linear displacement of the speed breaker simulated using ANSYS software. The weight converted in to a pressure because which is acting on the hydraulic oil and the pressure is applying on the upper surface of the piston. The geometry is designed using solid work software. Process of the simulation is as shown in the figure 3-21 below.

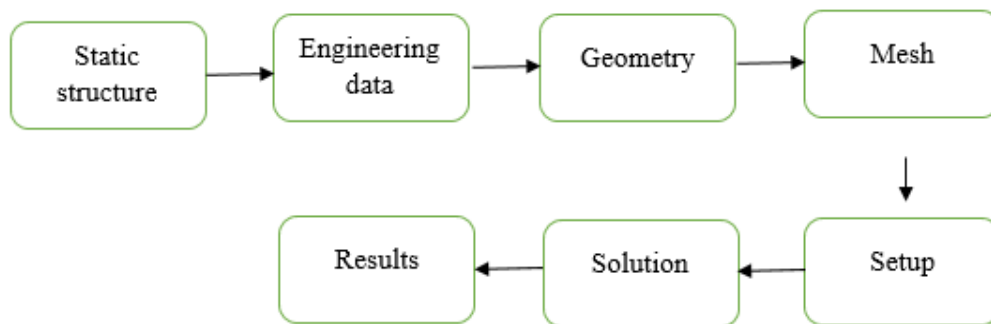


Figure 3-21 simulation process

Pre-processing of the simulation is selecting the type of simulation you need, selecting the engineering material, importion the geometry, meshing the geometryand then fix the boundary condition. Post-processing of the simulation is result analysis which is determining the muximum displacement of the rack and pinion mechanism when different pressure apply on the surface of the piston.

### 3.4.2. Static structural

ANSYS 19.2 (workbench) used to show static structural analyses in this case the displacement (X) are solved from the equation  $[K]\{X\} = \{F\}$  [38] where K is constant and F is the appied force. The speed breaker is static structure then when the vehicle travels over the speed breaker it will exerts force on it. the displacement of the speed breaker depends on the stiffness of the spring and the torque of the main shaft.

### 3.4.3. Geometry of the model $PG_1$

The geometry is designed using solid work software and imported to ANSYS it have three main components the lower piston, fixed support and the spring. According to the arrangangement when pressure applys on the upper surface of the piston the spring will deflect so the piston is connected to the rack the linear displacement will convert to the rotational motion.

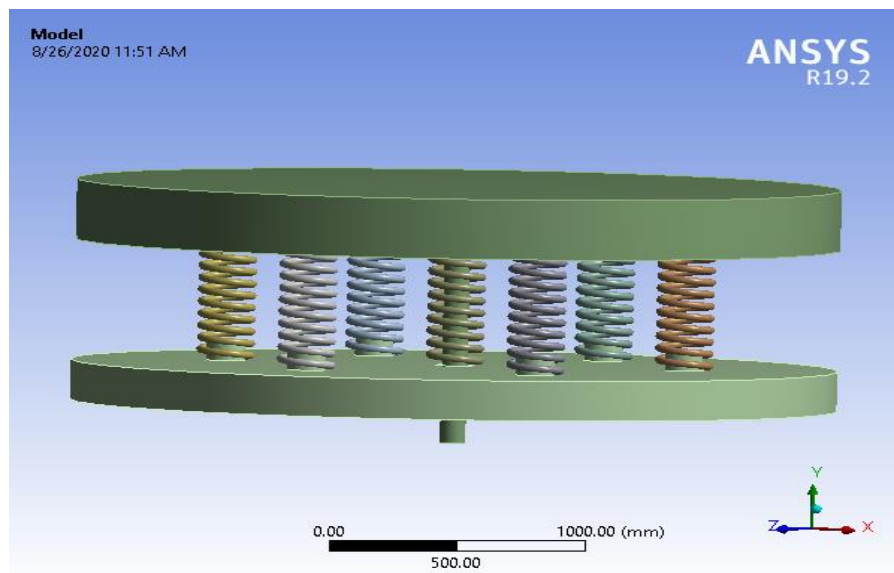


Figure 3-22 Geometry of Power Generation 1

According to the design principle of spring and the geometry of the model 7 springs are designed to compress when the vehicle apply load over the speed breaker, absorb and store energy and release the energy when the load removed. Power Generation 1 converts from 2000Kg to 3000Kg weight and the pressure developed inside the cylinder ( $P_i$ ) is between  $P_1$  and  $P_2$ . Springs are designed by considering the load of the pistons, dome and the load of the vehicle for the maximum deflection of the model so the dimenssions are as shown below.

<i>Name</i>	<i>Quantity</i>	<i>size in mm</i>
<i>Spring</i>	7	$d - 30$ $D - 200$ $n - 10$ $h - 400$ $P - 40$

Load acts on the spring is weight of the vehicle, weight of the two piston, weight of the hydraulic oil and the weight of the dome. Weight of the dome and the weight of the upper

## Electricity Generation from Hydraulic System Speed Breaker

piston is assumed 1000 Kg. Therefore, springs are designed in order to deflect 50 mm when 3000 Kg weight apply on the surface of the fluid. The geometry have three different components and the selected material for those components are as shown in the table 3-3.

Table 3-3 selected material for  $PG_1$

components	quantity	material
spring	7	stainless steel
piston	1	aluminum alloy
fixed support	1	structural steel

$PG_1$  Converts from 2000 Kg to 3000 Kg weight and the pressure developed inside the cylinder ( $P_i$ ) is between  $P_1$  and  $P_2$

Table 3-4 Pressure applying on  $PG_1$

Weight Kg	Piston1 and dome Weight	Total weight Kg	Pressure inside the cylinder in pascal or $N/m^2$
1000	1000	2000	11103.56
1200	>>	2200	12213.92
1400	>>	2400	13324.27
1600	>>	2600	14434.63
1800	>>	2800	15544.99
2000	>>	3000	16655.34

### 3.4.4. Geometry of the model $PG_2$

Working principal is same with  $PG_1$  but motion of the rack is horizontal, which is perpendicular to the motion of the rack  $PG_1$ . Pressure is acting on the front surface of the piston 3 and it is used to convert 3000 Kg to 8000 Kg weight in to electricity. In this case only one spring is used to restore the arrangement.

## Electricity Generation from Hydraulic System Speed Breaker

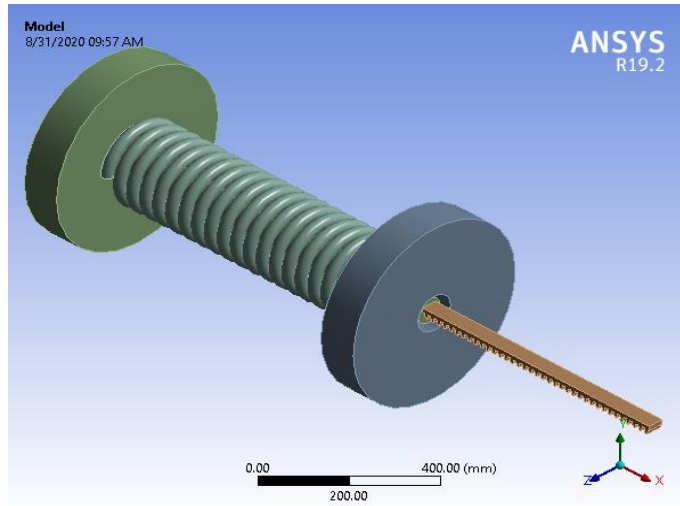


Figure 3-23 Geometry of Power Generation 2

The spring designed by considering where 8000Kg applying over the speed breaker and the maximum deflection is 120mm. Power Generation 2 is used to convert from 3000Kg to 8000Kg weight of the vehicle in to electricity and the pressure developed inside the cylinder ( $P_i$ ) is greater than  $P_2$ .

<i>Name</i>	<i>Quantity</i>	<i>size in mm</i>
<i>Spring</i>	7	$d - 30 \quad D - 200 \quad n - 20$ $h - 800 \quad P - 40$

Table 3-5 selected material for  $PG_2$

COMPONENTS	QUANTITY	METERIAL
spring	1	stainless steel
piston	1	aluminum alloy
fixed support	1	structural steel

$PG_2$  Converts from 3000 Kg to 8000 Kg weight and the pressure developed inside the cylinder ( $P_i$ ) is greater than  $P_2$

Table 3-6 Pressure applying on  $PG_1$

Total weight in Kg	Pressure inside the cylinder in pascal or $N/m^2$
3000	16655.34
4000	22207.13
5000	27758.91
6000	33310.69
7000	38862.47
8000	44414.26

**3.4.5. Boundary condition of  $PG_1$**

Where the vehicle apply load over the speed breaker pressure of the fluid inside the cylinder will increase. The simulation used to identify how much length the speed breaker moves downward. The geometry is tested by apply pressure on the upper surface of the piston and the bottom surface of the geometry is fixed. The spring and the force used to rotate the pinion is considered as a reaction force. Force needed to rotat the pinion is assumed 75 KN and the simulation is anlysis by applying pressure between  $P_1$  to  $P_2$  on the upper surface of the piston.

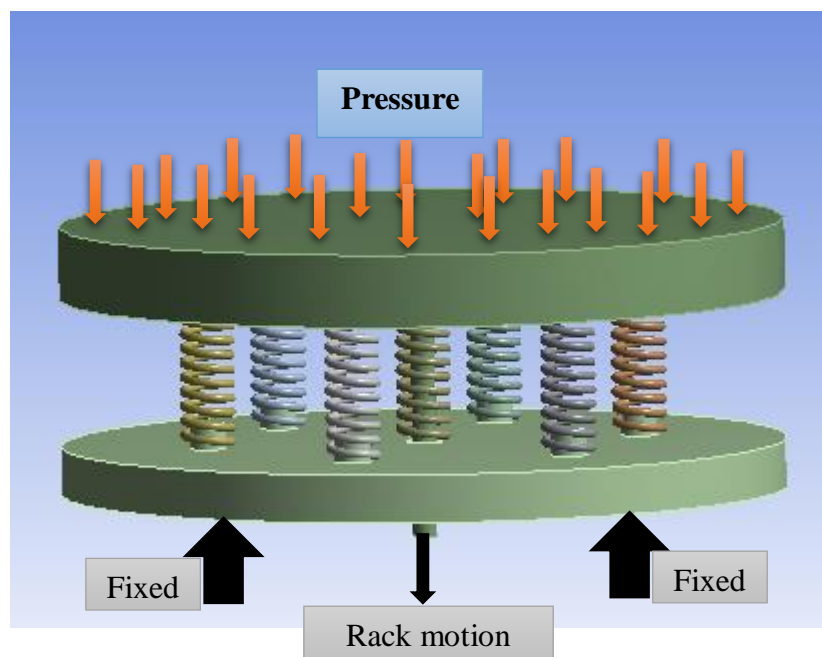


Figure 3-24 Geometry of  $PG_1$  and its boundary condition

## Electricity Generation from Hydraulic System Speed Breaker

In order to know the maximum time for the maximum displacement (50mm) of the piston when the pressure apply on the upper surface of the piston the maximum working pressure of power generation 1 is applying the result is shown in figure below.

### 3.4.6. Boundary condition of $PG_2$

If the vehicle exerts load more than 2000 Kg over the speed breaker  $PG_2$  starts to generate electricity. Pressure is applying on the front surface of the piston and the supporter is fixed when the pressure act on it the spring will deflect then there is horizontal motion on the rack. In this geometry 3 KN force considers as a reaction force used to rotate the pinion and the maximum length the rack will travel is 120mm. The simulation tested by applying six different pressures on the piston and the result is discussed.

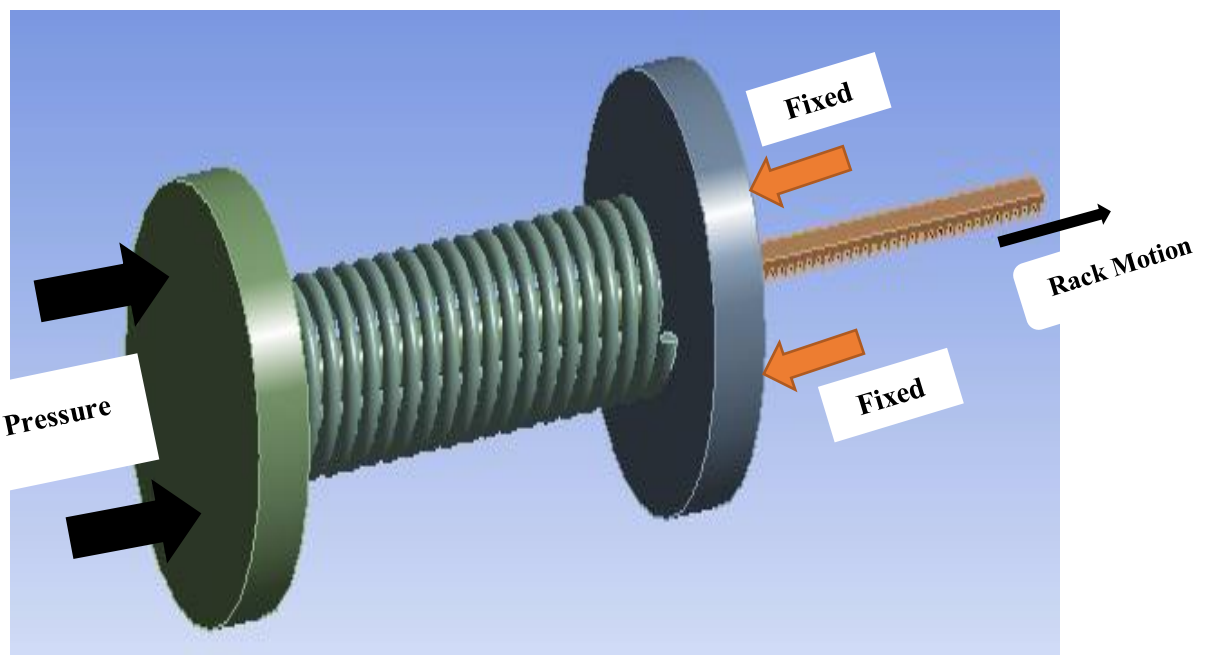


Figure 3-25 Geometry of  $PG_2$  and its boundary condition

This simulation helps to identify the time needed to deflect the spring and the deflection per pressure apply on the piston. The geometry is tested by applying 44414.26 pascal pressure in order to analyze the maximum time consumption for the maximum deflection of the spring.

### 3.4.7. Mesh optimization

Accuracy of the result and speed of the simulation time can be affected by the size of mesh element of the geometry[39], [40]. If the mesh is good solution is more accurate so mesh optimization is done in order to select better size of mesh element for the geometry[40]. In this paper finding the effect of mesh size on the numerical analysis result and choosing

## Electricity Generation from Hydraulic System Speed Breaker

the best mesh size for the simulation are provided. To analyze the effect of mesh size on the result from 1 – 10 cm element size tested on the simulation and the result is different except from 8 - 9 cm element size as shown in the figure below. The pressure applying over the piston for optimization of the mesh is 11103.56 pascal and the maximum deformation of the piston is 4.2 mm at 2 cm mesh size as shown in the figure below.

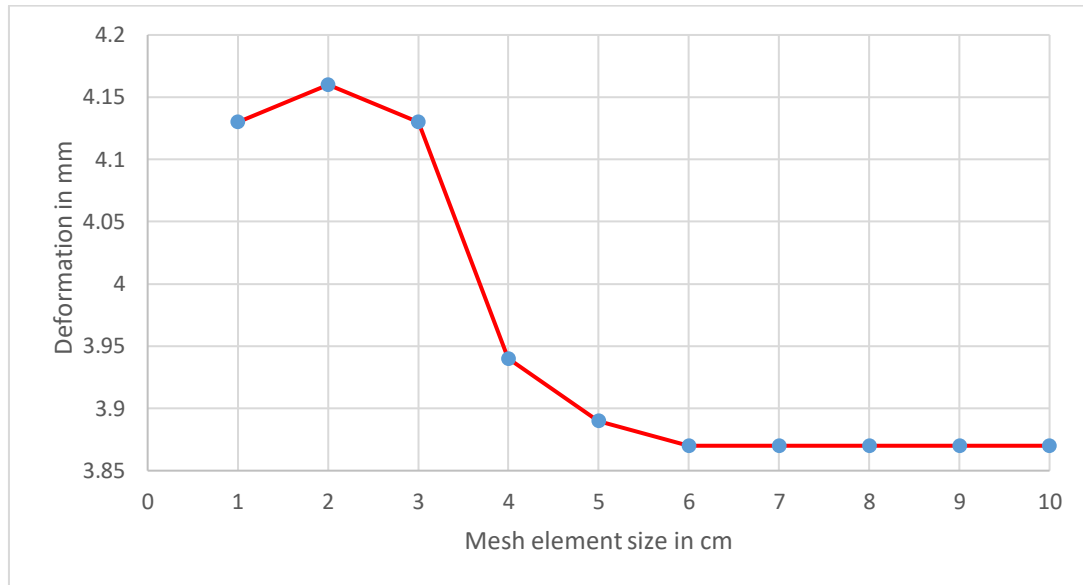


Figure 3-21 Element size versus Deformation

It is clearly shown in the figure above from 8 cm to 9 cm element size there is no variation in the solution. However, in this simulation study the element size mesh was taken from 6 cm – 10 cm because the deformation is constant 3.87 mm on those interval. Dimension of the spring is almost the same in case of  $PG_1$  and  $PG_2$  so mesh size optimization is similar. Therefore, during  $PG_2$  simulation element size is the same with  $PG_1$ .

### 3.4.8. Simulation analysis using the actual size of the prototype

This simulation is used in order to validate with the experimental result. The experimental investigation was taken by considering  $PG_1$  only. The geometry is designed using solid work software by using the prototype exact dimensions and imported to the ANSYS software for the simulation. The boundary condition is the same  $PG_1$ .

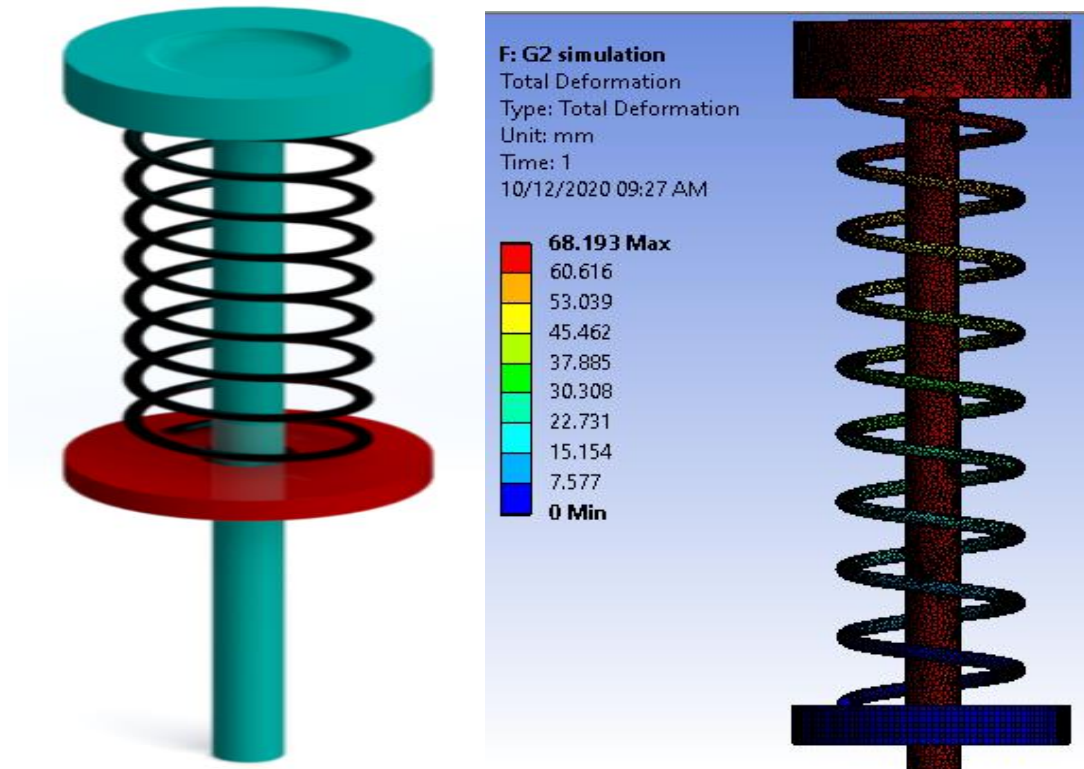


Figure 3-27 deflection result of the prototype model at one second

Diameter of the piston is 65 mm and the area is  $0.0033 \text{ m}^2$  by applying 0.029727 Mpa pressure which develops when 10 Kg load acts over the dome. The force needed to rotate the pinion which is considers as a reaction force to the pressure apply is 50 N and from the mesh optimization 3 mm element size is better. Therefore the simulation is done by apply a pressure (0.029727 Mpa) on the upper surface of the piston and the deformation result is as shown in the figure 3-27.

### 3.5. Experimental setup

Prototype is developed in order to convert weight in to electricity but it is not the actual size. However, because of the availability of the material, technology and cost here in this case only power generation 1 is develop as a prototype. Lathe machine, welding machine and drilling machine are used to manufacture of the prototype. In this mechanism during converting the weight of the vehicle over the speed breaker in to electricity different components are used. In the following section, the components and the development of the prototype will be shown.

#### Hydraulic cylinder

A hydraulic cylinder is a device, which converts the energy of fluid, which is in a pressure form into linear mechanical force and motion. In this thesis two cylinder with different diameter are provide to multiply the weight of the vehicle. And those two cylinder are join together using electric arc welding. However, this is single-acting cylinders it produce force in one direction by hydraulic pressure acting on the piston due to the vehicle weight. The return of the piston is not done hydraulically in single-acting cylinders; retraction is done by a spring.



Figure 3-28 Single-acting, spring-loaded, piston-type actuating cylinder

## Electricity Generation from Hydraulic System Speed Breaker

### Piston and connecting rod

Piston is circular in cross section it slides inside the hydraulic cylinder and provides guide to piston rod at one end. It assists the pressure energy in fluid to kinetic energy. In this case, two pistons are needed the outer diameter of the piston and the inner diameter of the cylinder is almost the same. Piston rod is a mechanical device, which transmit kinetic energy, which developed at piston, to the work-piece. It is circular in cross-section and two piston rod needed.



Figure 3-29 piston and the rack

### 'O' Ring

It is a ring with round cross-section, used to stop leakage between mating components of the hydraulic system and the piston. In this prototype 4 'O' rings 2 for the large piston and 2 for the small piston is wanted.

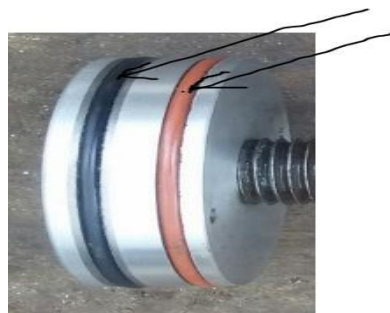


Figure 3-30 piston o ring

### Bearing

Bearings are machine elements which are used to support a rotating parts like shaft. They transmit the load from a rotating member to a stationary member known as frame. In this case, two bearings are fixed with the frame to support the main shaft.



Figure 3-31 bearing

### Gear

Gears are the most common part, which transmit power/motion between two shafts by meshing without any slip. In any pair of gears, the smaller one is called pinion and the larger one is called gear immaterial of which is driving the other. When small gear is the driver, the output speed decreases and the torque increases. On the other hand, when the large gear is the driver, the output speed increases and the torque decreases. Spur gears have their teeth parallel to the axis and are used for transmitting power between two parallel shafts. They are simple in construction, easy to manufacture and cost less. They have highest efficiency and excellent precision rating. It is used in high speed and high load application. By meshing a pair of these elements, they are used to transmit rotations and forces from the driving shaft to the driven shaft. However, in this case the force coming from the hydraulic system speed breaker have high torque we need to convert that force to high speed so the large gear is the driver fixed with main shaft and the small gear if driven which is fixed in the DC motor.



Figure 3-32 gears

### Spring

Springs are a mechanical element that compress under load, absorb and store energy and release the energy when the load is removed. However, springs are broadly classified as helical spring, leaf spring and disc spring but in this case; helical spring is preferable as they are made of wire coiled into a helical form, the load being applied along the axis of the helix. Maximum spring compression "maximum travel considering solid height" of the upper spring is 12cm and the lower spring is 6cm that means the spring can travel safely without any permanent set caused by fatigue and stress. In this case two helical springs are used to lift the speed breaker after the vehicle passes over it. The upper helical spring is used to lift up the solid part and the lower helical spring is used to lift up the hydraulic oil.



Figure 3-33 springs

## Electricity Generation from Hydraulic System Speed Breaker

### Rack and pinion

Rack and Pinion is composed of two gears the flat helical gear is the rack and the round helical gear is the pinion. The rack has teeth cut into it and they mesh the teeth of the pinion gear. Main objective of rack and pinion is to convert the linear motion coming from the hydraulic oil or piston to rotational motion also a large spur gear is connect to the shaft of the pinion, which is mesh with the small gear. However, the rack is connect with the lower piston and when the vehicle passes over the speed breaker there is linear motion on the rack that motion will convert to the rotational motion through the pinion. The pinion and the large gear is fixed on the main shaft supported by the bearing.



Figure 3-34 rack and pinion

### Shaft

It is a rotating element, used to transmit power from one place to another place and torque. For the prototype, round steel 35mm diameter used to mount the gears and the rack. The shaft mounted on bearings to provide for resistance free rotation about its own axis. The loads acting on the shaft are that of the weights of the components mounted on the shaft, transmission loads and self-weight of the shaft.



Figure 3-35 fixed shaft Assembled

### Hydraulic fluid

Hydraulic fluids have the primary purpose of transferring potential or kinetic energy (pressure and movements) from the upper piston to the lower piston and due the area difference of the piston head the force exerted by the lower piston will twice of the weight of the vehicle. In addition, the hydraulic fluid/oil used as cooling system and lubrication it helps to increase the lifetime of the machine. The hydraulic fluid is one of the most important design factor in hydraulic system and should be consider as a machine element.

*Hydraulic fluid has to perform the following tasks:*

- ✓ Energy transmission
- ✓ Multiply the force
- ✓ Smooth motion
- ✓ Lubrication
- ✓ Heat removal

## Electricity Generation from Hydraulic System Speed Breaker

For any application, the features of the hydraulic fluid must be appropriate to the operating environment of the unit and its components. For the prototype due to the size of the two cylinder 2 litter, hydraulic oil is enough.



Figure 3-36 hydraulic oil

### Energy conversion

DC generators supply power to a load circuit by converting the mechanical energy of some prime mover into electrical energy. The prime mover must rotate at a definite speed in order to produce the desired voltage. However, the energy transformed from one form to another so, we can simply use generators which convert rotational mechanism to get electrical energy in this case electrical DC motor used as a generator to convert the mechanical energy of the shaft to electricity for the prototype 220 – 240V DC motor and power rated 500W is enough. It is considers as the simplest types of motor used in many of the electrical appliances. Compared to the AC motor, it is more controllable and powerful. Then the energy will store in battery and stored energy can utilized for many other applications.



Figure 3-37 DC motor

## | Electricity Generation from Hydraulic System Speed Breaker

**Frame:** - used to hold the components together



Figure 3-38 Frame holding all the components used

## Electricity Generation from Hydraulic System Speed Breaker

### Preparation of the prototype for testing



Figure 3-39 Prototype at testing site

### 3.6. Instruments used to measure the output

1. **Linear distance measuring tools (meter)** used to measure the linear motion when the load applying over it.



Figure 3-40 measuring the length

2. **Multimeter:** Used to measure the output voltage and current when the load apply.

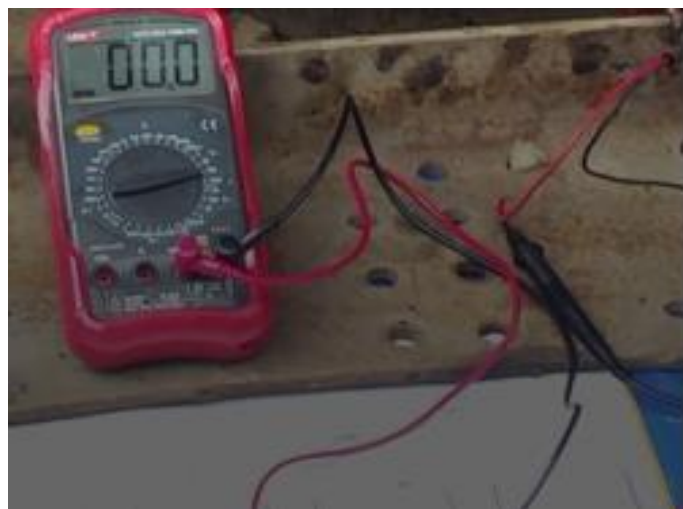


Figure 3-41 multimeter

### 3.7. Measuring methods

In order to calculate the output power of the prototype the voltage is measured with load condition because current is measured if there load or resistance only. In addition to show the possible maximum voltage produced when different load apply on the dome the voltage is measured with no load condition.

#### A. Measuring voltage with load condition

In this method of measuring the output voltage of the prototype, the load (5-watt lamp) is placing parallel to the multimeter and the dynamo.

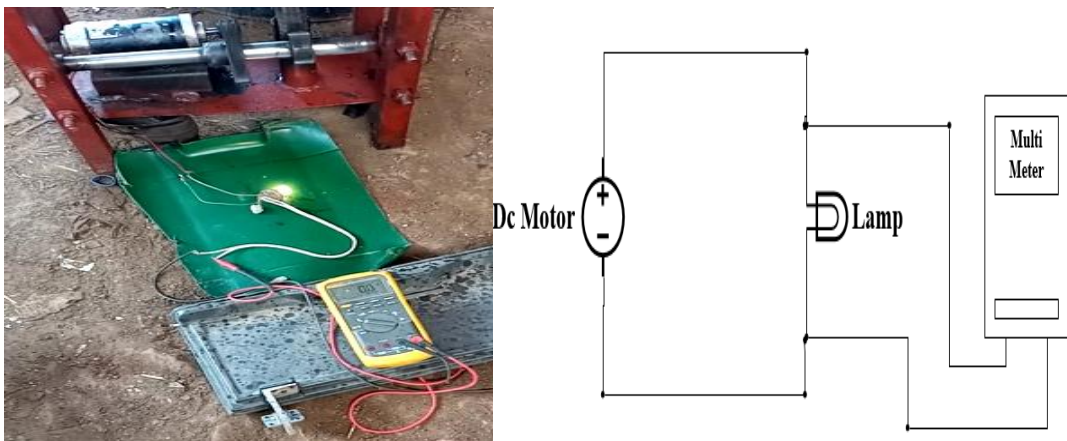


Figure 3-43 voltage measuring with load condition

Voltage is related to how fast the dynamo is rotating and weight is a matter to rotate the pinion also in order to increase the speed of the pinion. The faster it rotate, the higher the voltage output from the dynamo.

#### B. Measuring voltage with no load condition; The measured voltage is used to show the possible maximum output voltage

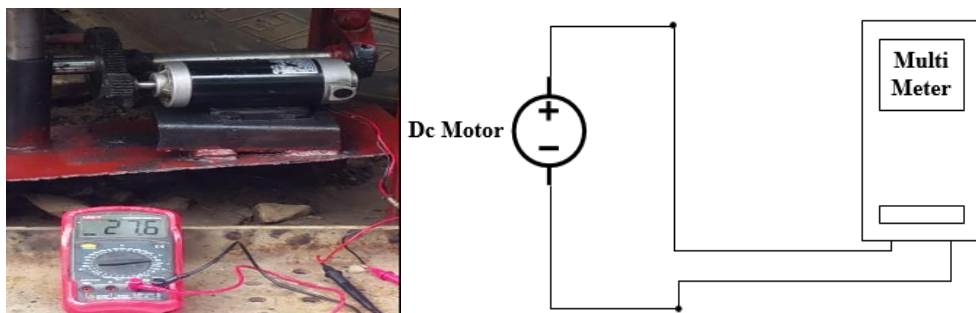


Figure 3-42 voltage measuring with no load condition

### C. Measuring current with load condition

To measure current with load condition, place a load (5-watt lamp) in series then when we apply weight on the dome of the prototype the dynamo is forced to do some work. The way to measure current with load condition in a circuit is to break the circuit open and insert a Load in series with the circuit as shown in Figure 3.44.

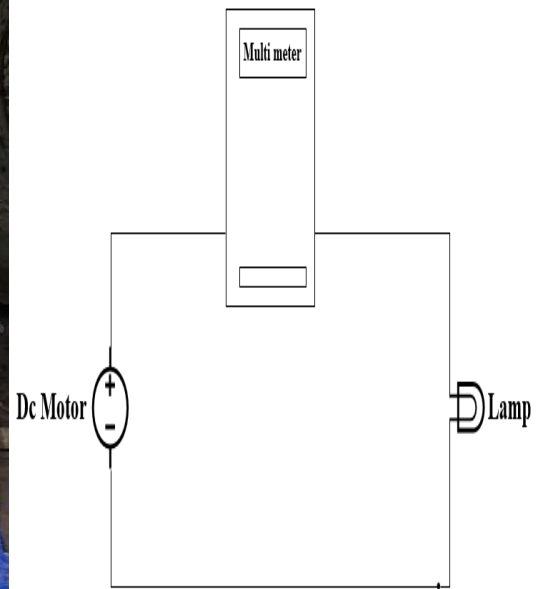


Figure 3-44 current measuring with load condition

The output current that the model produces depend on the weight apply on the dome or the pinion torque generated by the weight. To calculate the output power from the model prototype, we will need the measured voltage and current with load condition. The result of the prototype is discussed in the chapter four.

## CHAPTER FOUR

### RESULT AND DISCUSSIONS

#### 4.1. Experimental Result

Experimental test was taken out by manufacturing the prototype and placing on the testing site. The result and discussion is shown in this section contains load versus voltage, load versus current, load versus displacement and load versus the output power. The prototype was tested by applying load (5Kg, 10Kg, 18Kg, 20Kg and 30Kg) on the dome. The output voltage with load and current with load condition was discussed in this section. The length of the dome moves downward when the load apply on it was also measured. During this experimental testing, the load applied is vertical and all loads assumed as sudden load. The prototype was designed by considering 30 Kg for the maximum deflection of the spring. Input parameter for the experiment result is load, and the output is voltage and current so the result was affected due to the efficiency of the DC motor, efficiency of the gear and the spring. The prototype was tested by keeping constant load and repeated five times to observe the change on the voltage output and the determination factors of the model is speed, time and length of the speed breaker.

##### 4.1.1. Voltage output with load condition (5-Watt lamp)

The experiment was provided by applying constant weight five times and taking five result observations for different weights. The output voltage and current measured at 5-watt lamp as a load condition connected in to the wire. How to measure the voltage with load condition is discussed in the methodology section chapter 3. The experimental result is as shown figure 4-1.

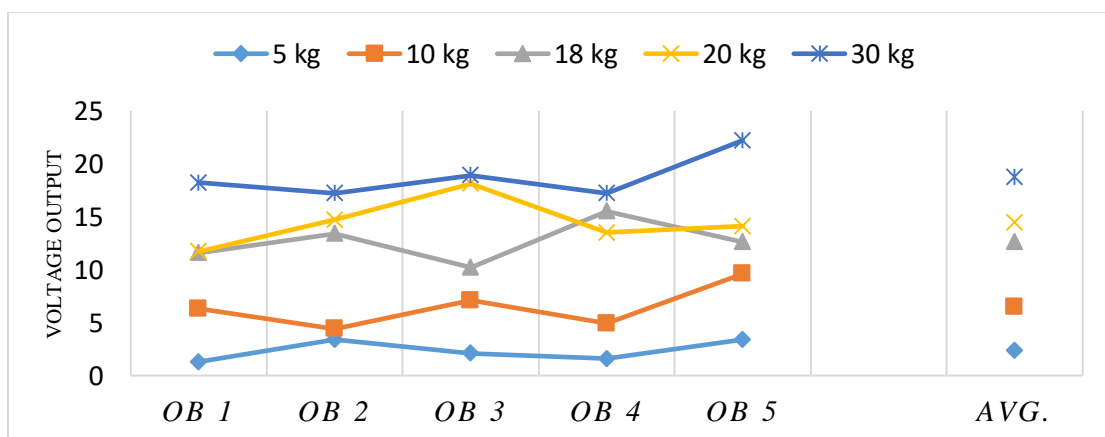


Figure 4-1 output voltage in five observation

## **Electricity Generation from Hydraulic System Speed Breaker**

The maximum voltage observed from the experimental results are 3.4, 9.6, 15.5, 18.1, and 22.2 volt when 5, 10, 18, 20 and 30 Kg weight applying over the dome respectively. This result is used in order to know the power output from the prototype by multiplying with the output current. However, we cannot measure current with no load condition, power is the product of voltage and current so in order to calculate we should have to measure with the same condition. Figure 4 - 1 shows voltage result is different even when we provide external load condition by applying constant load in different frequency because of sudden load. This experimental result is taken by applying constant load and the output voltage is measured using multimeter.

However, the weight of the vehicle considers as a sudden load so even the vehicle those have the same weight travels through the speed breaker the voltage output was not the same. due to that the prototype tested by applying constant load five times, to identify the average output voltage. At 5 Kg weight the output voltage in five observation, vary from 1.3 to 3.4 volt and the average voltage output is 2.36 volt at 30 Kg weight the output voltage vary from 17.2 to 22.2 volt and the average voltage is 18.74 volt. The variation on the voltage output is due to the sudden load applying on the dome. So in order to know the output power of the prototype we should have to use the average voltage. From the experiment, it observed that the maximum voltage is produced when 30 Kg load applying on the dome so increasing the load over the dome is cause for the maximum power production.

### **4.1.2. Current output with load condition (5 lamp)**

The experiment was repeated five times as the voltage measured above and the average current of the reading noted is considered as current output of the prototype when corresponding load is applied. From the result, five different output current is observed at a constant weight applying with load condition (5-watt lamp) connected on the output voltage.

## Electricity Generation from Hydraulic System Speed Breaker

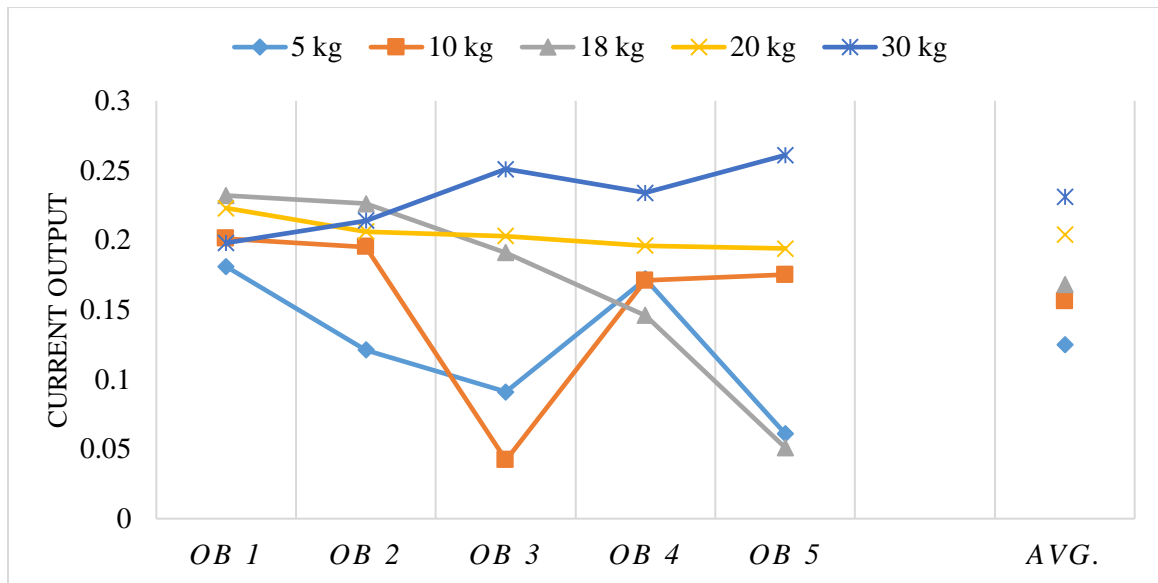


Figure 4-2 Current output in different observation

From the above experimental result, it is observed that increasing the load on the speed breaker will result for increasing on the current output. So the output current of the system is depends on the pressure inside the cylinder and the pressure depends on the weight of the vehicle. Sometimes the variation is high due to applying the weight suddenly with high speed and slow speed, which is random because we have to consider that the vehicle passes through the speed breaker have different speeds. However, for the calculation of the power output of the model the average voltage and the average current is used.

### 4.1.3. Weight versus the Output Power

By applying different load the average output voltage and average output current was calculated and discussed in the above figures 4-1 and figure 4-2. The prototype is designed to convert the weight between the interval from 5 to 30 Kg and it is know that the output power is electrical power and calculated using the formula  $P = V \times I$ . the result shown in the figure 4-3.

## Electricity Generation from Hydraulic System Speed Breaker

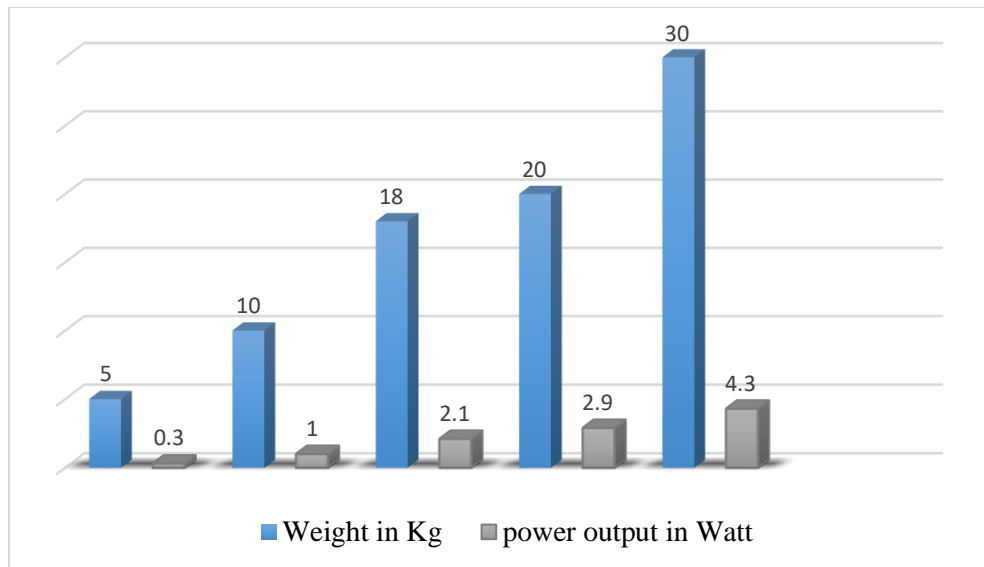


Figure 4-3 weight versus power output

Power output vary due to the variation of weight applying over the dome and it is also influenced by the stiffness of the spring and torque of the pinion. The experimental result shows the output power depends on the weight or as weight increase; the output power is also increase. If the stiffness of the spring is less the output power is high but the spring cannot restore the dome in to the original level and if the stiffness is high the output power is less. From this experimental testing at 20 Kg weight it is observed that with small weight vitiation the output power variation is high. From this experiment, it is possible that if we implement this technology in large scale we can generate more electricity (in Kw power) per one push of the speed breaker if heavy vehicles are pass through it.

### 4.1.4. Length traveled

After applying the load on the dome, how much length the dome travel downward were measured. In this case, five observation provided then the average length is used to calculate the input power by multiplying with the weight.



Figure 4-4 measuring the length travel

The Measured length in five different observation shown in the figure below.

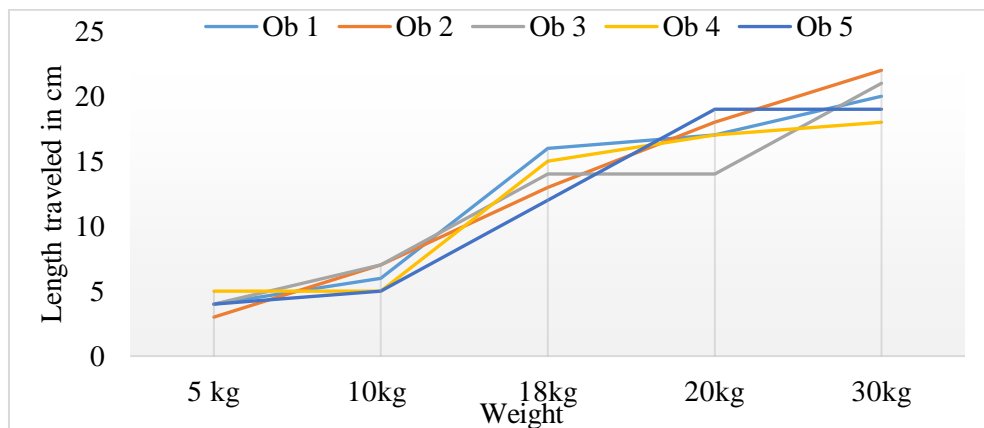


Figure 4-5 traveled length versus load

The above figure shows the variation of the dome travels downward in different weight acting on it in five observations. The average length travels of the dome is 4, 6, 14, 17 and 20 cm when we apply 5, 10, 18, 20 and 30 Kg weight respectively. The maximum deflection is shown when 30 Kg weight apply on the dome which is 22 cm.

### 4.2. Efficiency of the new prototype

The efficiency of the new prototype depends on the mechanical transmission system and the generators. However, the expected energy lose in the prototype is due to the friction induced between the piston head and the cylinder internal surface, the rack and pinion mechanism, and the gearbox and the generator energy lose. The overall efficiency of the prototype is the ratio between the power output from the model and the power input so the power output is power input minus the energy loses. The input Mechanical power is the rate at which work is done where as an object is moved over a certain distance. Power is

## Electricity Generation from Hydraulic System Speed Breaker

either the rate of production of energy or the rate of use of energy. Work is the force exerted on object times the distance over which the force is exerted. The force acting over the upper piston is the weight of the front axle of the vehicle. According to the experimental result, the output power is known which is the product of the output voltage and the output current. The prototype of the model is developed by considering the availability of the material due to that the efficiency may not as expected. From equation 1.3 to calculate the efficiency of any system by dividing the output work to its input work and multiplying that number by 100.

$$\text{Efficiency of the Model (\%)} = \frac{\text{output power from the model (V} \times \text{I)}}{\text{Input power (Weight} \times \text{Length traveled/time)}} \times 100$$

Weight is the load of the vehicle over the dome and when this load is applied, the length the dome travels downward per the time consumption for the maximum deformation. In addition, the time is time taken by the vehicle to pass the speed breaker dome, and this depends on the speed of the vehicle. To know the efficiency of the prototype first 10 Kg weight was applied on the dome then dome downward distance traveled was found 6cm and the time taken for the maximum deflection of the dome was 2 second. Therefore, overall efficiency ( $\eta_o$ ) of the model prototype

$$\eta_o = \frac{1 \text{ Watt}}{2.943 \text{ Watt}} = 0.3399$$

$$\eta_o = 33.99 \% \approx 34 \%$$

### 4.3. Validation simulation result with experimental result

The simulation was done by taking the exact dimensions of the prototype and designing using solid work then importing to the ANSYS 19.2 (workbench). According to the simulation, the deformation observed when we apply 0.029727 Mpa pressure over the upper surface of the piston was 68mm. force needed to rotate the pinion is assumed 50 N. therefore from equation (1.1) work is force exerted on the pinion multiplying by the distance traveled or the deformation of the piston. In addition, from equation (1.2) power is the rate at which work is done or the amount of time in which the work is done. Mathematically the input power is

$$P = \frac{50 \text{ N} \times 0.068 \text{ m}}{1 \text{ second}} = 3.4 \text{ Watt}$$

## Electricity Generation from Hydraulic System Speed Breaker

The above result is theoretical, which is the input power without considering the efficiency of transmission system rack and pinion arrangement, gear and the DC motor. In this model rack and pinion is proposed to convert the reciprocating motion to the rotational motion which is input to the gearbox approximate efficiency is about 95% [41], [42]. Efficiency of the gear is generally greater than 98% if the torque is not in very low level[43]. Approximate range of external spur gear efficiency is 97 to 99% [44]. In this case, DC motor is used as a function of generator, which converts the mechanical energy to the electrical energy. The DC motor used to build the prototype is a product of Ningbo made in china rated power 500 Watt DC 220 – 240 volt input voltage. According to the Ningbo DC, motor performance report December 2019 if the torque is greater than 0.7 Nm the efficiency of the motor is approximate 80% [45]. Therefore, overall efficiency of the model is by multiplying the efficiency of the rack and pinion assumed 95% , efficiency of spur gear assumed 98% and efficiency of the DC motor assumed 80%. Overall efficiency of the model is 74%. As the experiment investigation taken by applying 5, 10, 18, 20 and 30 Kg load over the dome the simulation is also done by considering if we apply those load upon the dome what will be the pressure inside the cylinder also acts on the upper surface of the piston and different deformation was observed. The output power from the simulation will be calculated by considering the efficiency of rack and pinion, spur gear and the DC motor. Comparison between the experimental power output and the simulation result is shown in the figure 4-6 below.

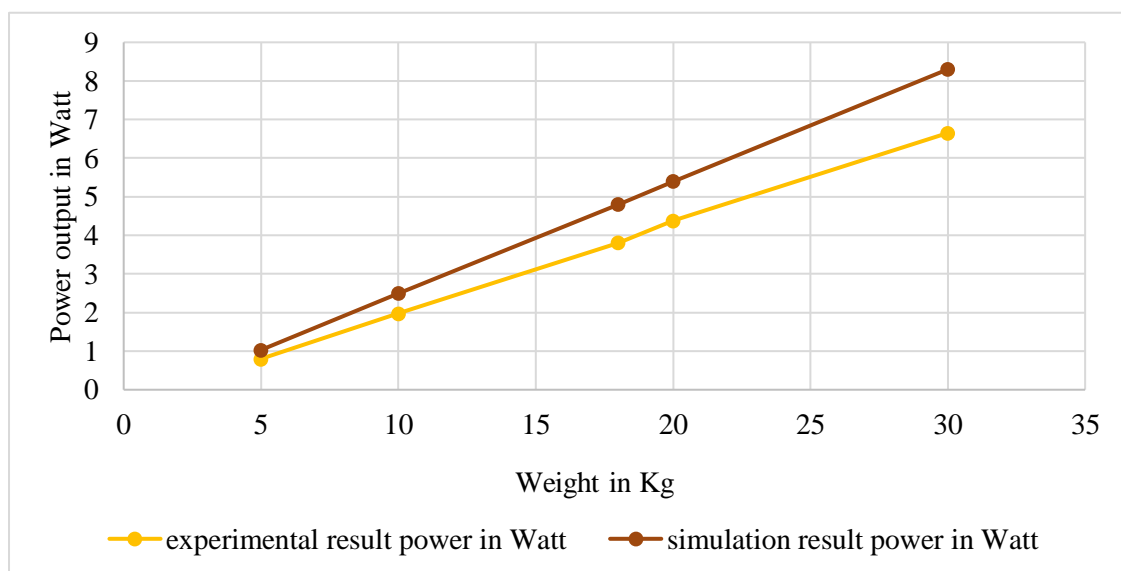


Figure 4-6 comparison of experimental and simulation result

## **Electricity Generation from Hydraulic System Speed Breaker**

Figure 4 - 6 shows that the comparison between the experimental results and the simulation result. The experimental result is power output by calculating the voltage and current observed and simulation result is power that is calculated by multiplying the displacement shown when we apply the pressure and reaction force divided by the time taken. There is a variation the experimental result is lower than the simulation result relative error vary between 23% to 28 % the maximum relative error is at 5 Kg load because at starting time the piston needs high load in order to move down ward due to the friction. Relative error is high because of the friction between the piston side surface and the internal surface of the cylinder in addition; the material used to build the prototype is second hand so the efficiency of the DC motor and the transmission system can affect the experimental result output. However, during manufacturing the prototype in order to have a good surface finishing and providing a good clearance between the piston and the cylinder was challenging so the friction between them is high due to that the output power is reduced. Here in this case in order to validate with the simulation the experimental testing is done by removing the upper spring because the simulation is taken by considering the lower spring only.

### **4.4. Comparison of electricity generation from HSSB with other previously done researches**

The main objective of this research were to asses the existing technology, and do an experimental investigation by developing a model prototype. Thereby improve the efficiency of the existing technology and to increasing the power productivity. Accordingly, the output power from the newly developed model prototype was mesearred and when compared to the other existing technology improvements were observed. Thus in this research power productivity and efficiency are the two basic parameters used to make a comparison between the prototype developed in this thesis with the already existing technology which was applied on the previously done researches and the comparisons made between the prototype and the previous technology are summarized in Table 4-1.

Table 4-1 comparison using the output power

[New Prototype] using HSSB with Rack and Pinion Mechanism		[Jyoti Maurya] using Rack and Pinion Mechanism		[Pooja Gupta] using Rack and Pinion Mechanism	
Load in Kg	Power output in Watt	Power output in Watt	Power output in Watt	Power output in Watt	Power output in Watt
5	0.3	-----	-----	0.112	-----
10	1	-----	-----	0.31	-----
20	2.9	0.23	-----	-----	-----
30	4.3	0.35	-----	-----	-----

Jyoti Maurya develops a prototype for the case of experimental testing the size is almost the same with this new prototype prototype but the output power observed is very less. When 20 Kg and 30Kg load, apply over the prototype dome the result was 0.23544 and 0.35316 watts respectively whereas in the prototype prototype the output power was 2.9 and 4.3 watts this result shows the prototype increases the power productivity and the efficiency was improved. And Pooja Gupta also done an experimental investigations with almost the same prototype with new used in this research the result power output 5 and 10 Kg load apply is 0.112 and 0.31 respectively this is also relatively very small when we compare with new result. In this research, a working prototype was constructed and an experimental study result by taking 6 Kg of load, the efficiency calculated approximate 10% and the prototype from the experiment result the efficiency of the prototype is approximately 34% therefore according to the result efficiency is improved. However, the efficiency is improved due to using hydraulic system speed breaker this helps in order to have a smooth motion power lose due to vibration is minimized. The vibration cause for the high friction lose it is a reason to reduce the efficiency of the system. In addition, the hydraulic fluid in this case is used to multiply the force in the output of the lower piston this helps in order to provide high torque on the pinion this torque is input to the gearbox.

## **Electricity Generation from Hydraulic System Speed Breaker**

Therefore, the output speed from the gearbox is high due to this relation efficiency of the transmission system is also high at high torque and speed.

As per an experimental study result considering different weights conducted on energy recovery using ratchet mechanism causing displacements in rack and rotating the pinion contacted with the DC motor to measure the voltage and current produced [16]. The result of voltage and currents are directly proportional to the force-applied just like the new prototype. The input mechanical power applied, output electrical power generated and the efficiency is calculated. The maximum efficiency observed at 50 Kg weight the input mechanical power calculated at a given force applied was 21.875 Watts and the output result electrical power observed was 7.020 Watts therefore overall efficiency of the system is 32%. In this paper only rack and pinion mechanism with chain drive mechanical transmission system are used due to that reason vibration is induced and it can produce effects on the efficiency of the system. The maximum efficiency observed on this research is 32 % then the maximum efficiency of the new prototype experimental result at 10 Kg load applied is 34% this shows 2% efficiency improvement. Therefore, electricity generation using HSSB have better efficiency and the output power is relatively good if we compare with the other existing mechanisms. However, the new prototype the hydraulic system helps in order to have smooth motion, easy to control and used for the purpose of lubrication to reduce friction.

### **4.5. Estimated energy production by the actual size using the analysis software**

By using the simulation result, it is possible to estimate the output power and generating capacity by considering the standard efficiency of the gearbox, rack and pinion arrangement and the generator to estimate overall generating capacity of the plant. In this model rack and pinion was proposed to convert the linear motion of the hydraulic system to the rotational motion that is input to the gearbox approximate efficiency is about 95% [41], [42]. In this case, gearbox was used to increase speed and reduce torque that comes from hydraulic system speed breaker. The rotational motion input to a gearbox have high torque and low speed, which used to maximize the generator input speed and to reduce the torque. Gearbox have better efficiency than the chain drive system and it have large speed ratio. Efficiency of the gearbox is approximate 97.65% at the torque of 35 Nm and 2000 RPM rotational speed[27]. The DC generator (direct current generator) which is a kind of

## Electricity Generation from Hydraulic System Speed Breaker

electrical machine and used to convert mechanical power into DC type electricity [46]. here in this research two DC generators are used. Without considering, the efficiency the components used the recommended DC generator for  $PG_1$  should have to be generate power between the interval of 0.1 KW to 2 KW and the maximum power generated from  $PG_2$  is up to 0.4 KW. This type of DC generator is used for small power supply and INNOTECH power technology, is a custom design and manufacturer of DC generator with peak efficiency is over 93% and this DC power directly feeds into the battery bank or direct in to the DC power load[47]. Therefore, overall estimated efficiency of the proposed prototype power production is the product of efficiency of the rack and pinion mechanism, efficiency of the gearbox and efficiency of the DC generator so by considering those three components the approximate overall efficiency is estimated 85%.

### 4.5.1. Displacement result of the Simulation

Displacement of the piston was simulated using ANSYS static structure analysis and the assumed reaction force applied on the rack is 75KN for  $PG_1$  and for  $PG_2$  is 3KN. The permissible maximum displacement of  $PG_1$  is 50mm and for  $PG_2$  is 120mm.

#### Displacement Result in case of $PG_1$

The first simulation is by applying 2000Kg weight of the vehicle or 0.016655 Mpa pressure over the upper surface of piston to know the maximum time consume for the maximum deflection.

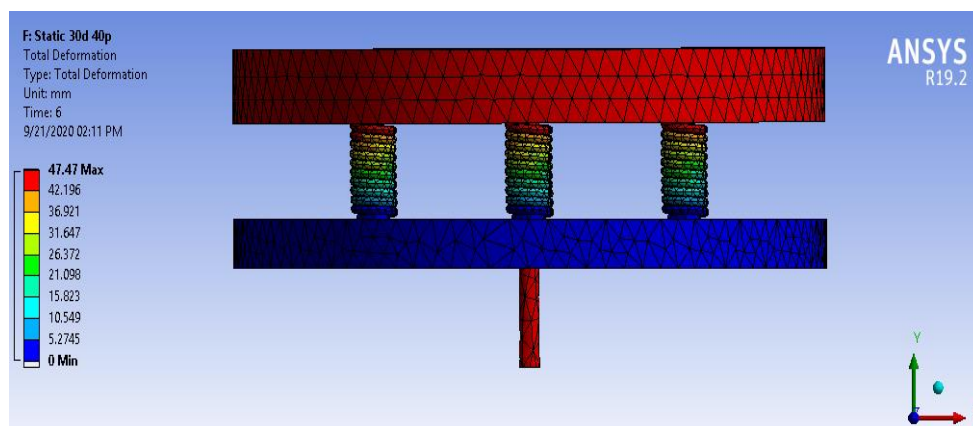


Figure 4-7 Deformation result of the simulation at 0.016655 Mpa pressure Deformation is how much the geometry are being displaced from their normal position when the pressure apply on it. However, the red colour shows the maximum displacement of the geometry and the blue one is the minimum value of the displacement.

## Electricity Generation from Hydraulic System Speed Breaker

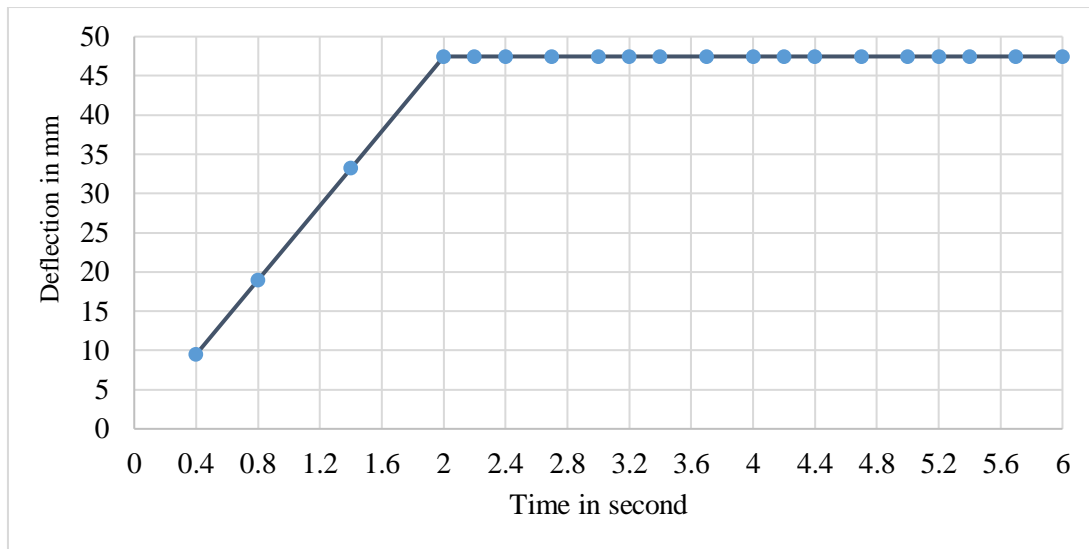


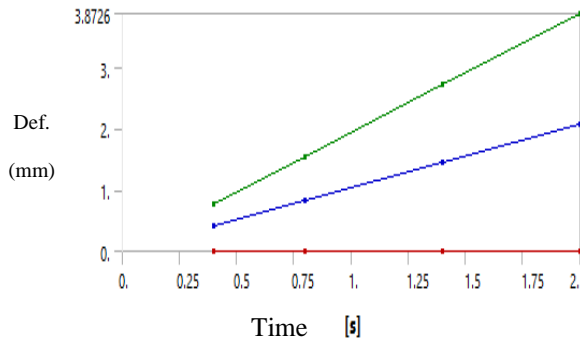
Figure 4-8 deflection versus time at constant pressure (0.016655 Mpa)  $PG_1$

From the above simulation result shown the maximum time for the maximum deflection was 2 sec, after 2 sec the deflection was fixed even the vehicle stays on the speed breaker we can not generate electricity because there is no motion on the rack and if the vehicle pass the breaker less than that time it is possible to generate but for the maximum power the vehicle will have to stay for two second. Therefore the vehicle that have 2000Kg weight in order to generate more electricity should have to stay over the speed breaker for 2 sec.

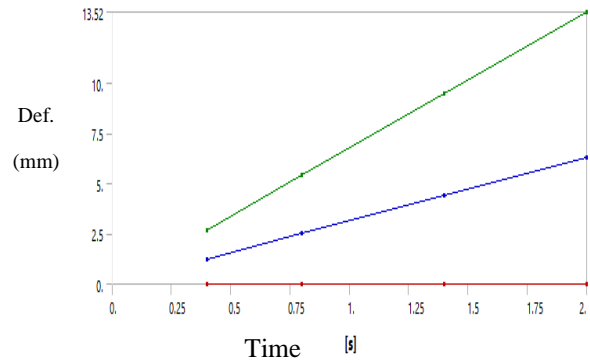
### Time and deflection at different load of the vehicle on Power generation 1

The relation between the time and the maximum deflection of the spring at different load of the axle is as shown in figur 4-9. Therefore the deflection depends on the load of the vehicle and also the time.

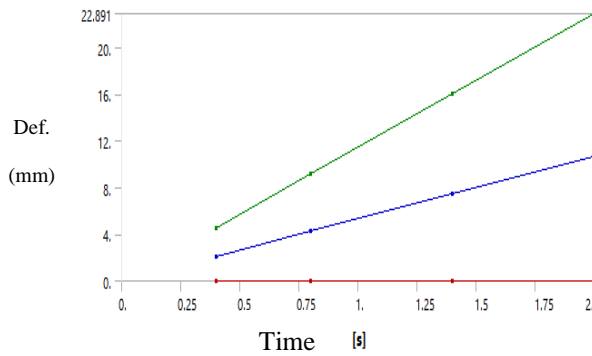
## Electricity Generation from Hydraulic System Speed Breaker



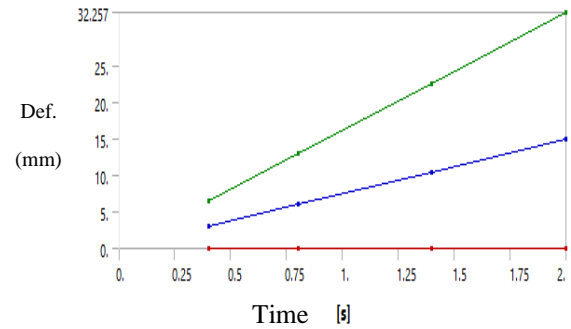
Deflection versus time at 2000Kg load



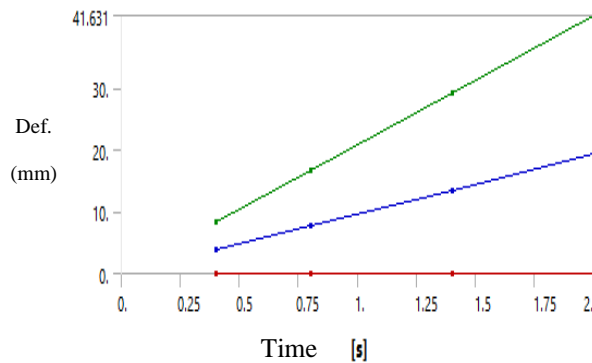
Deflection versus time at 2200Kg load



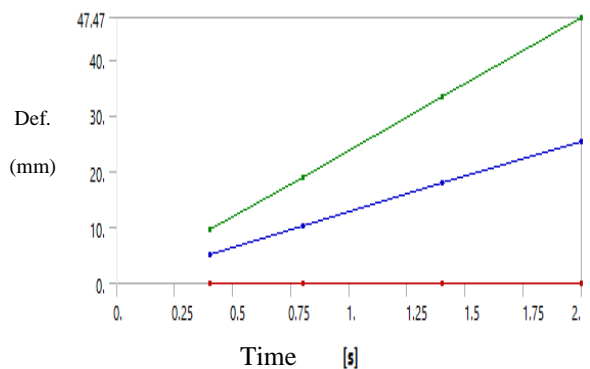
Deflection versus time at 2400Kg load



Deflection versus time at 2600Kg load



Deflection versus time at 2800 Kg load



Deflection versus time at 3000 Kg load

Figure 4-9 Deflection versus time at different load applying over the speed breaker dome

The simulation above shows when the time increase until two second the deflection also increase that means the relation between time and deflection is direct proportional until two second in power generation 1. As shown on the figure above when the load increase the deflection also increase. However, from the simulation above observed in power generation 1 the power output is depends on the time and load applying on the speed breaker. Power output increases when the applied load over the speed breaker increase.

### Deflection result in case of $PG_2$

To identify the time for the maximum deflection of the spring we have to apply maximum permissible pressure for power generation of the model over the speed breaker. Therefore, in this case the maximum pressure for power generation was 44414.26 pascal.

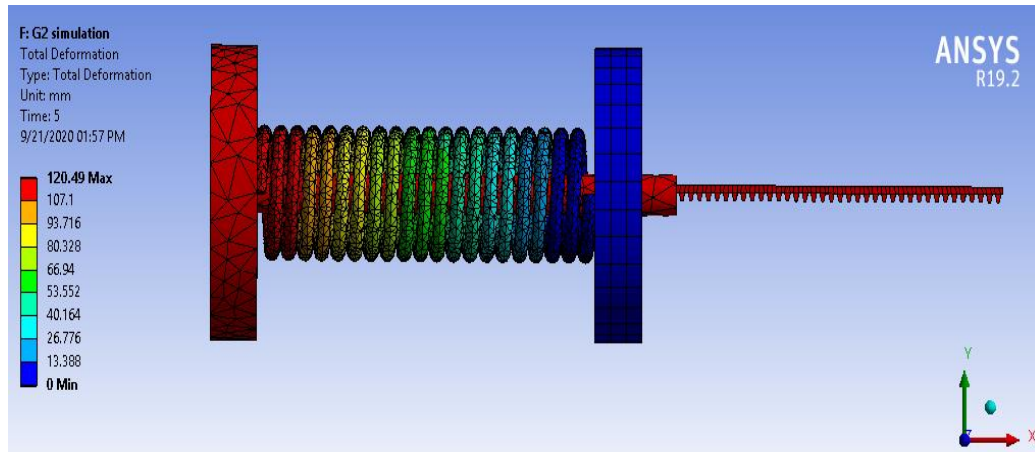


Figure 4-10 Deformation result of the simulation at 44414.26 pascal pressure

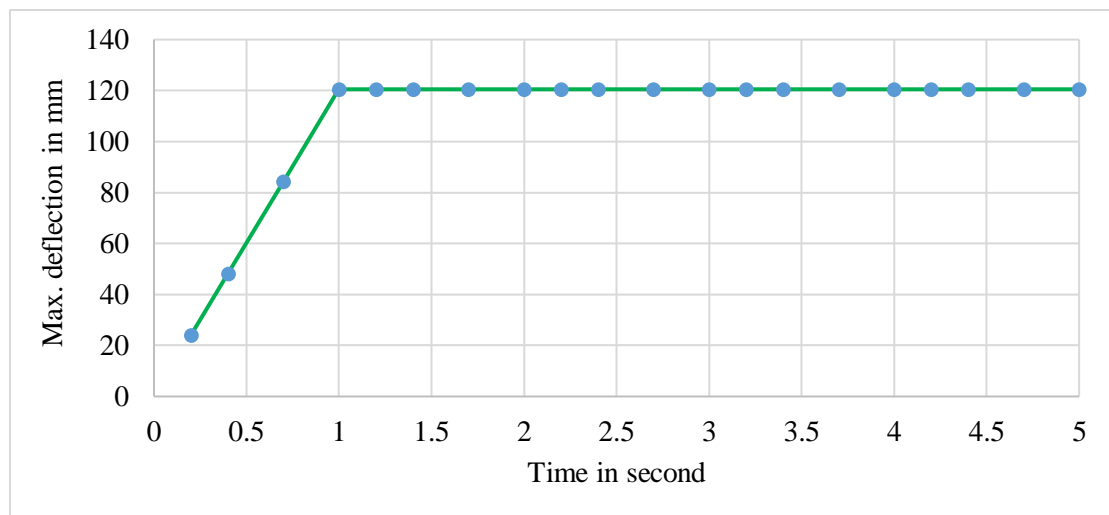
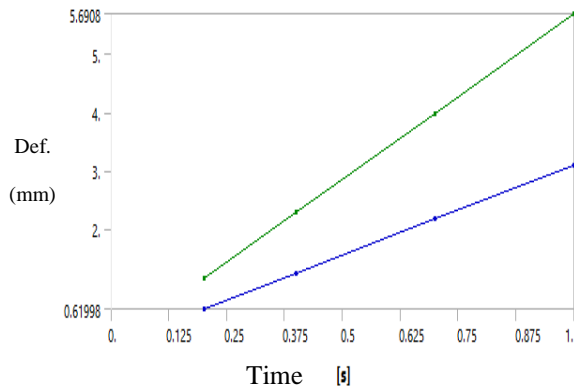


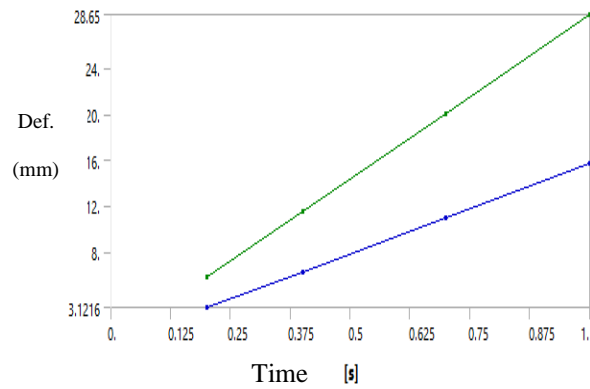
Figure 4-11 deflection versus time at constant pressure(44414.26 pascal)  $PG_2$

According to the simulation, the result shown in the figure 4-11 the maximum deflection is 120.49mm at the time of 1 second. After one second, the deformation is constant that means there is no motion on the rack or the system cannot generate electricity.

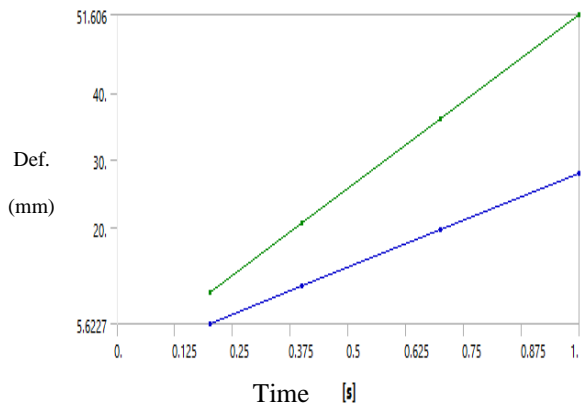
## Electricity Generation from Hydraulic System Speed Breaker



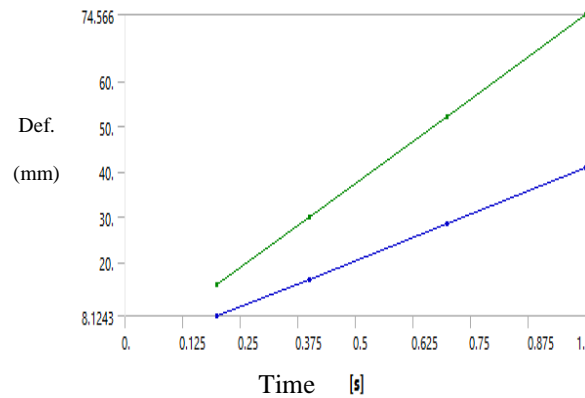
Deflection versus time at 3000Kg load



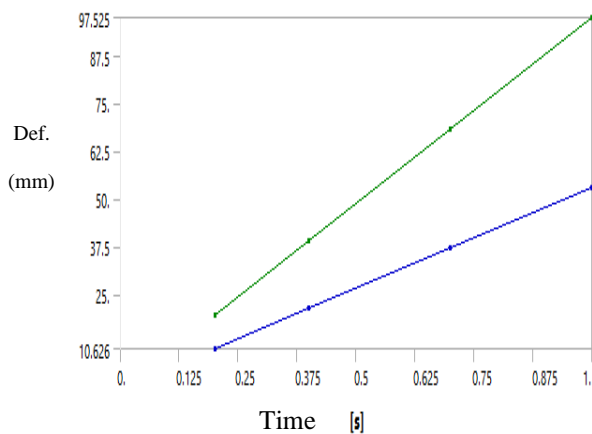
Deflection versus time at 4000Kg load



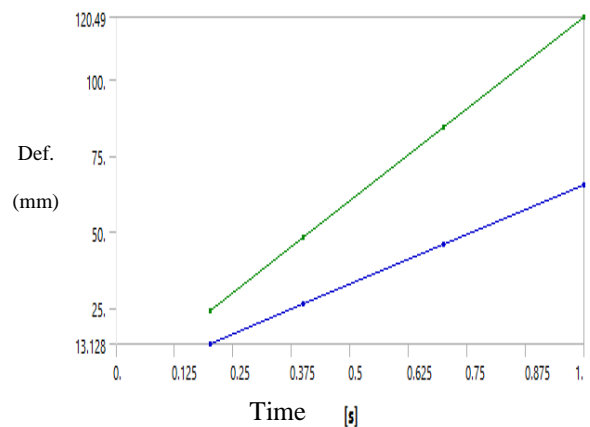
Deflection versus time at 5000 Kg load



Deflection versus time at 6000 Kg load



Deflection versus time at 7000 Kg load



Deflection versus time at 8000 Kg load

Figure 4-12 Deflection versus time at different load applying over the speed breaker dome

According to the simulation, the maximum time taken for the maximum deflection of  $PG_1$  is two second and for  $PG_2$  is one second after this second the deflection is constant. Mechanical power is the rate at which work is done as an object is moved against opposition over a certain distance. Power is either the rate of production of energy or the rate of use of

## Electricity Generation from Hydraulic System Speed Breaker

energy. The maximum displacement result observed from the simulation of  $PG_1$  and  $PG_2$  at different weight is as shown in the figure below.

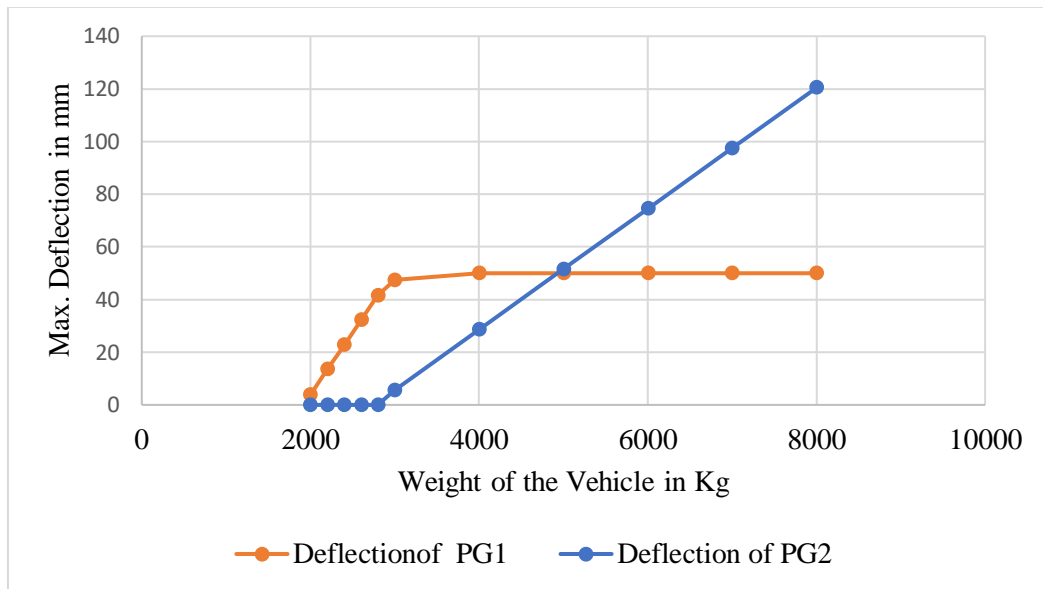


Figure 4-13 weight versus maximum deflection

Figure 4-13 shows the maximum deflection observed from the simulation result when load applying from 1000 Kg to 7000 Kg with considering 1000 Kg weight of the dome and the upper piston. Therefore, the simulation was taken by applying overall possible weight acts on the fluid from 2000 Kg to 8000 Kg. If weight of the vehicle that have less than 1000 Kg passes through the speed breaker dome as we see in the figure the deflection is zero that means there is no electrical power generation at all. The result shows until 3000 Kg weight apply on the dome surface  $PG_2$  will not generate electricity because there is no motion on the rack it means mechanical power is zero at no motion.  $PG_1$  starts to generate electricity when 1000 Kg weight of the vehicle apply on the surface of speed breaker dome until 2000 Kg plus 1000 Kg weight of the upper piston and the dome total 3000Kg weight electricity is generated continuously. After 3000 Kg weight the deflection of the piston is constant which is 50 mm because the spring is designed by considering 50 mm maximum deflection at the maximum permissible weight of the vehicle. Therefore, for all weights greater than 3000 Kg applying over the speed breaker will not generate electricity in case of  $PG_1$  because of no motion produced on the rack.  $PG_2$  Starts to generate electricity when 3000 Kg weight apply on the upper surface of the fluid and the deflection is direct proportional to the weight of the vehicle acts on the dome. There was horizontal motion until 8000 Kg weight apply on the upper surface of the fluid this means electricity was generated when the weight between 3000Kg to 8000 Kg apply on the upper surface of fluid in case of  $PG_2$ .

### 4.5.2. Estimated power production

This model have two-power production unit the arrangement was as discussed in the methodology section and the system was designed to produce power when any vehicle passes through it. By applying different weights on the working model, displacement was simulated using ANSYS software and by assuming the efficiency of components, the estimated results from the prototype as shown in the figure 4-14 below.

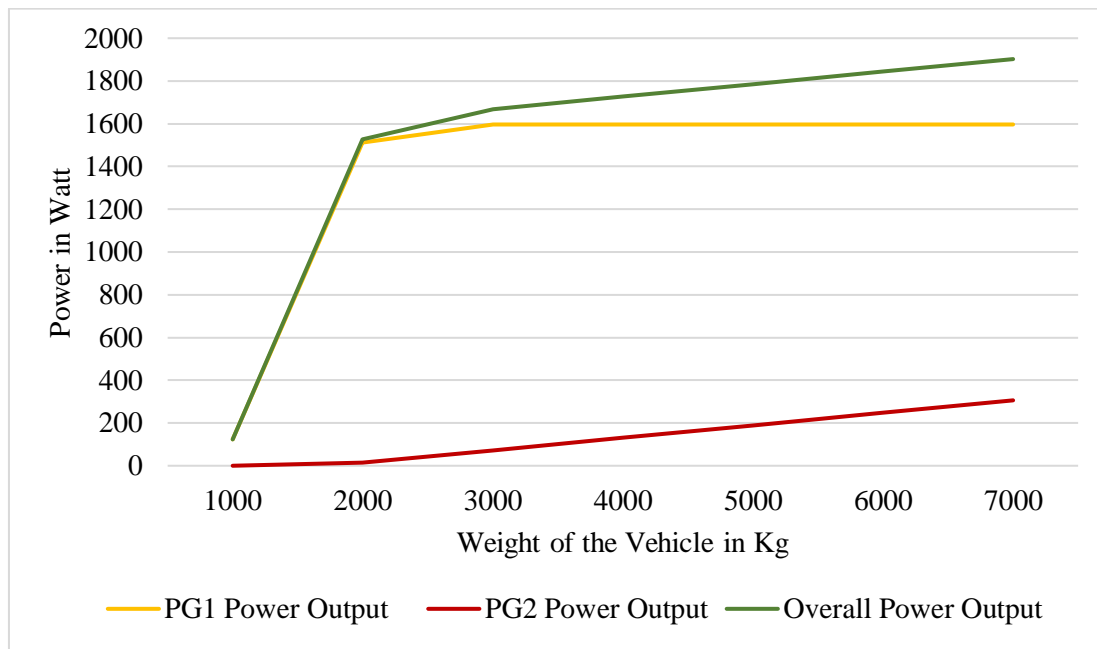


Figure 4-14 weight versus estimated power output

$PG_1$  is used to convert 1000 to 2000 Kg weight of the vehicle without considering the weight of the upper piston and the dome as shown in figure 4-14 until 3000 Kg weight the output power is slightly increased. After 3000 Kg weight even the weight increase, the output power is constant. According to the weight interval of the vehicle and length of the speed breaker travel from the simulation result  $PG_1$  generates from 123.25 to 1902.3-watts power per one push of the speed breaker.  $PG_2$  Starts to generate electricity if the vehicle passes through the speed breaker have more than 2000 Kg weight per axle so as shown in figure 4-14 it has the capacity to generate from 17-watt to 306-watt power. However,  $PG_2$  could not generate electricity if the vehicle that have less than 2000 Kg weight passes over the speed breaker. Overall, the plant generates from 123.25 to 1902.3-watt power per one push and it depends on the weight of the vehicle. Therefore, power productivity is increase by adding the power generation station.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1. Conclusion

This research introduces the prototype, which is electricity generation from hydraulic system speed breaker. In addition, experimental investigation by develop a prototype and simulation analysis using ANSYS 19.2 (workbench) was done. Variation of the vehicle weight is under consideration in the design of the model. Efficiency was improved as compared to the existent technology due to using hydraulic system speed breaker. For the hydraulic system helps to have smooth linear motion on the speed breaker. In addition, stiffness of the spring and height of the speed breaker is fixed but force applying on the dome was different due to the variation of vehicle weight so that affects the efficiency of the model. In this case, hydraulic fluid is easy to control even if the variation of the vehicle weight travels through the speed breaker is high and can be managed using two or more power generation station for different interval of weight of the vehicle.

From the result observed of the technology used in the prototype, the mechanism used for power generation is helpful to increase electricity access in Ethiopia. The prototype needs a modification for the purpose of large-scale electricity generation. According to the experiment and the simulation result observed the following conclusions are drawn.

- ✚ From the experimental result observed when weight apply on the dome increases voltage with load condition (5-watt lamp) and Voltage with no load condition increases and the result of current with load condition (5-watt lamp) also increases. Therefore, weight of the vehicle and number of vehicle passes through the speed breaker is direct proportional to the power output of the model.
- ✚ According to the simulation result, increasing the vehicle speed over the dome reduces the length of downward motion of the rack due to that the output power generated from the model become reduced.
- ✚ Downward motion of the speed breaker depends on the weight of the vehicle, diameter of the wire, pitch length of spring and the cylinder geometry.
- ✚ Increasing in the height of the speed breaker helps to increase the power output but the standard maximum height of the speed breaker is 15cm.
- ✚ Electricity generation through hydraulic system speed breaker is environmental friendly and the floor area required to install is comparatively less.

- ✚ Efficiency was improved by using hydraulic system speed breaker

### 5.2. Recommendation and future work

- I. This process of power generation can be affected in rainy season if the underground water transmission line is not working properly. Therefore, to implement this technology proper design of underground water transmission pipe in the selected site is necessary.
- II. However, without implementation in busy road, this process of power generation is nothing at all because electricity generation from this model depends on the number of vehicle travel over the speed breaker if less number of vehicle moves through the selected road power production is less.
- III. This technology does not propose to build new speed breaker for the purpose of electricity generation rather it is encouraging practically to implement where already existing speed breakers are available.
- IV. The performance of fluid power transmission can increase by using good surface finishing on the internal surface of the hydraulic cylinder and piston head. In addition, proper size of hydraulic seal can cause for the efficient fluid transmission.

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## Appendix

➤ **Cylinder and its material properties**

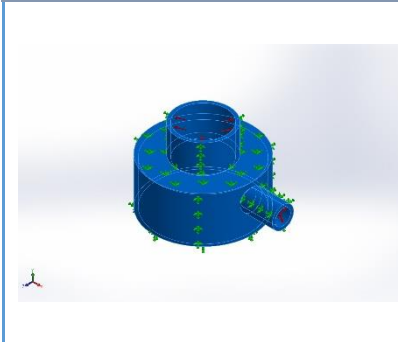
Model Reference	Properties
	<p>Name: <b>Stainless Steel</b></p> <p>Yield strength: <b>1.72339e+08 N/m<sup>2</sup></b></p> <p>Tensile strength: <b>5.13613e+08 N/m<sup>2</sup></b></p> <p>Elastic modulus: <b>2e+11 N/m<sup>2</sup></b></p>

Figure A-1 Cylinder and types of material selected with properties

➤ **Cylinder stress analysis**

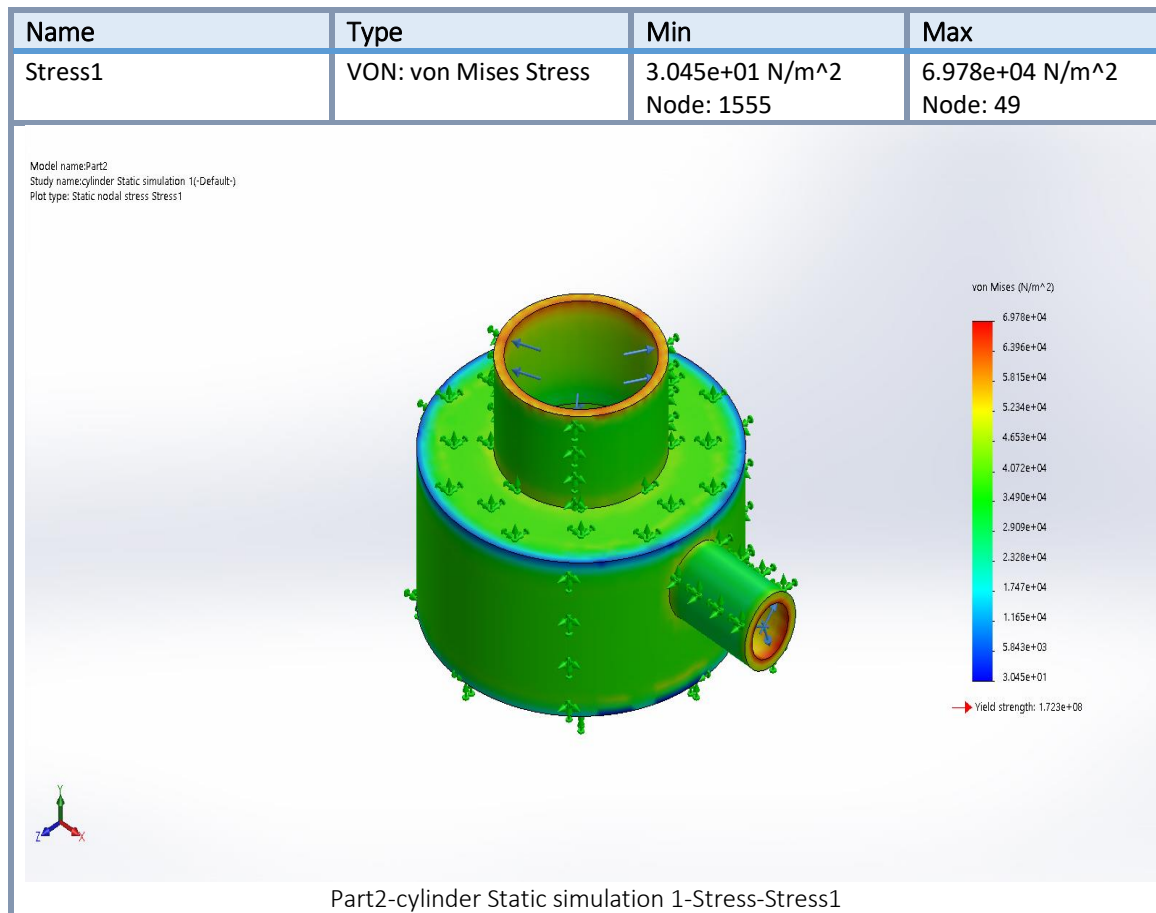


Figure A-2 Stress analysis result of the cylinder

# Electricity Generation from Hydraulic System Speed Breaker

## ➤ Cylinder displacement analysis

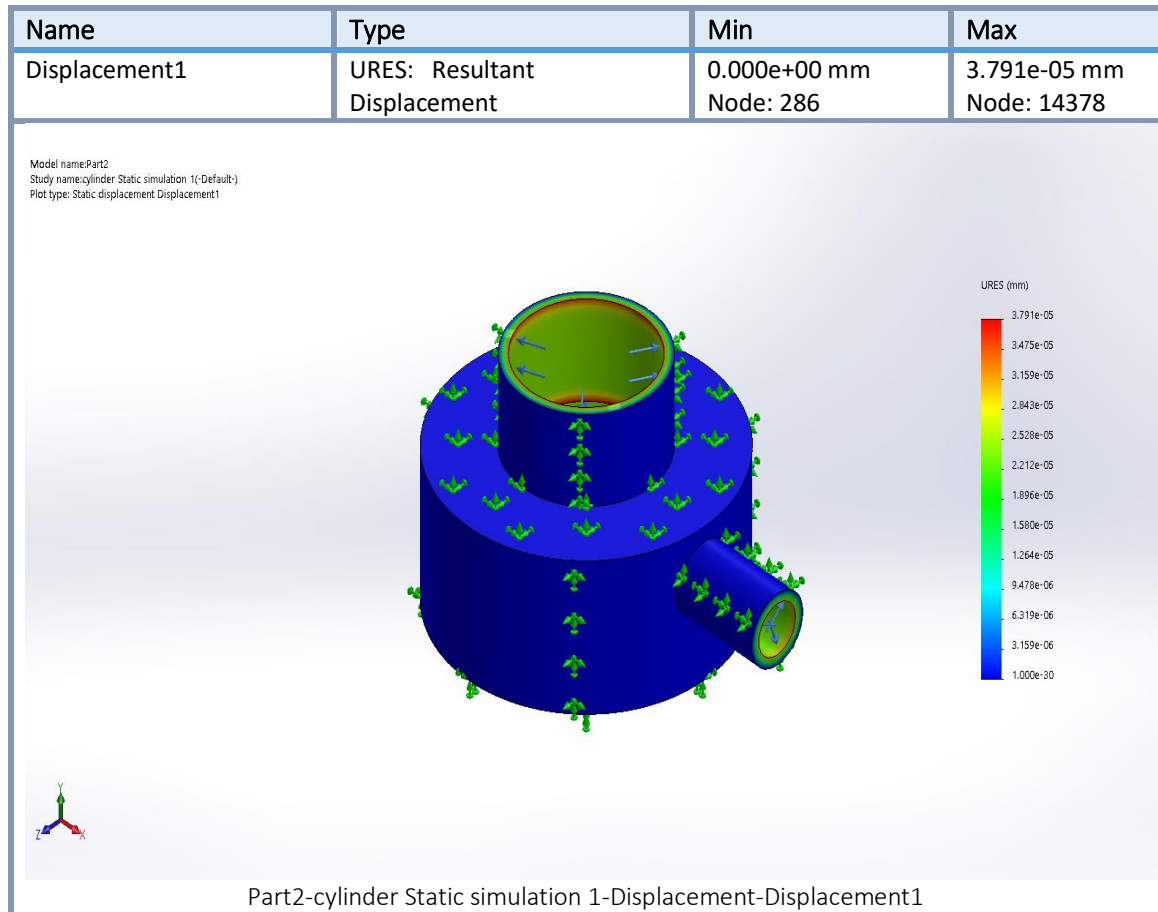


Figure A-3 Displacement analysis result of the cylinder

# Electricity Generation from Hydraulic System Speed Breaker

## ➤ Piston and material properties

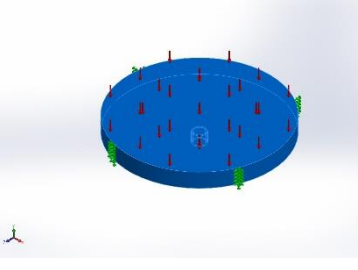
Model Reference	Properties
	<p>Name: <b>1060 Alloy</b></p> <p>Yield strength: <b>2.75742e+07 N/m<sup>2</sup></b></p> <p>Tensile strength: <b>6.89356e+07 N/m<sup>2</sup></b></p> <p>Elastic modulus: <b>6.9e+10 N/m<sup>2</sup></b></p>

Figure A-4 Piston and types of material selected with properties

## ➤ Piston stress analysis

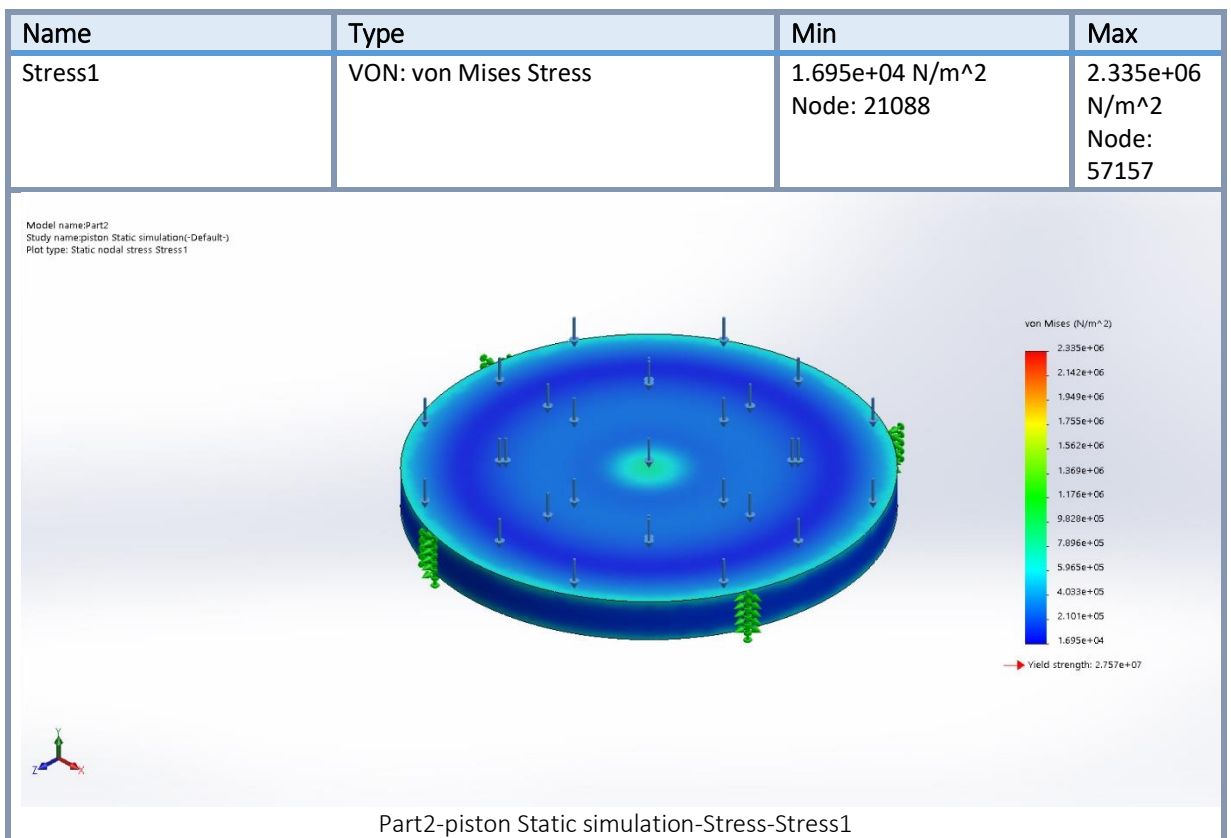


Figure A-5 Stress analysis result of the piston

# Electricity Generation from Hydraulic System Speed Breaker

## ➤ Piston displacement analysis

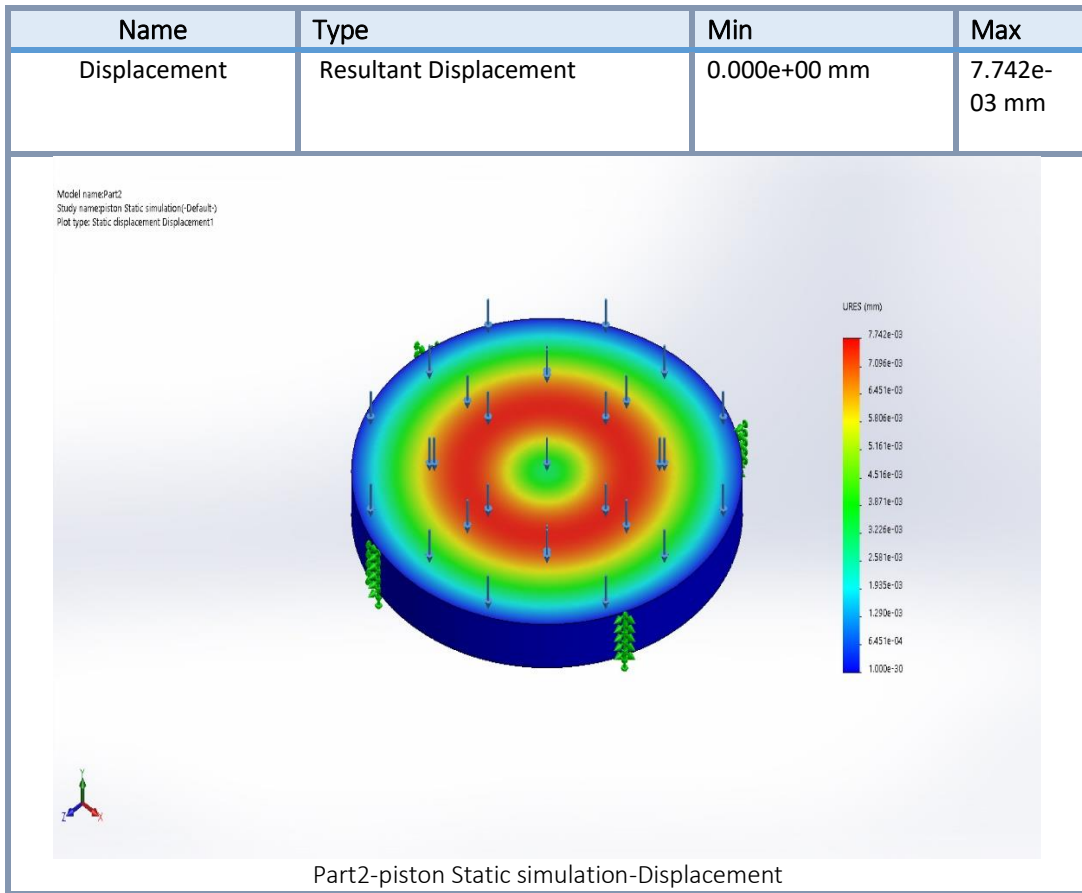


Figure A-6 Displacement analysis result of the piston

## Electricity Generation from Hydraulic System Speed Breaker

### EXPERIMENTAL RESULT

Table A-2 Weight, Voltage Output and Length Traveled

S. No	Weight in Kg	Parameters	Observation no. 1 Voltage produced in volt And Length traveled in cm	Observation no. 2 Voltage produced in volt And Length traveled in cm	Observation no. 3 Voltage produced in volt And Length traveled in cm	Observation no. 4 Voltage produced in volt And Length traveled in cm	Observation no. 5 Voltage produced in volt And Length traveled in cm	Avg. voltage produced in volt And Length traveled in cm
1.	5	Output voltage	1.3	3.4	2.1	1.6	3.4	2.36
		Length traveled	4	3	4	5	4	4
2.	10	Output voltage	6.3	4.4	7.1	4.9	9.6	6.46
		Length traveled	6	7	7	5	5	6
3.	18	Output voltage	11.6	13.4	10.2	15.5	12.6	12.66
		Length traveled	16	13	14	15	12	14
4.	20	Output voltage	11.7	14.7	18.1	13.5	14.1	14.42
		Length traveled	17	18	14	17	19	17
5.	30	Output voltage	18.2	17.2	18.9	17.2	22.2	18.74
		Length traveled	20	22	21	18	19	20

## Electricity Generation from Hydraulic System Speed Breaker

Table A-2 Experimental result Voltage output by Appling different weight

Weight In Kg	Ob. 1.	Ob. 2	Ob. 3	Ob. 4	Ob. 5	Avg. voltage produced in volt
5	1.3	3.4	2.1	1.6	3.4	2.36
10	6.3	4.4	7.1	4.9	9.6	6.46
18	11.6	13.4	10.2	15.5	12.6	12.66
20	11.7	14.7	18.1	13.5	14.1	14.42
30	18.2	17.2	18.9	17.2	22.2	18.74

Table A-3 Experimental result Output current by applying different weight

S. No	Appling load in Kg	Observation no. 1 Current produced in Amp	Observation no. 1 Current produced in Amp	Observation no. 1 Current produced in Amp	Observation no. 1 Current produced in Amp	Observation no. 1 Current produced in Amp	Avg. Current produced in Amp
1.	5	0.181	0.121	0.091	0.172	0.061	0.125
2.	10	0.201	0.195	0.042	0.171	0.175	0.156
3.	18	0.232	0.226	0.191	0.146	0.051	0.168
4.	20	0.223	0.206	0.203	0.196	0.194	0.204
5.	30	0.198	0.214	0.251	0.234	0.261	0.231

## | Electricity Generation from Hydraulic System Speed Breaker

Table A-4 Experiment and simulation result summary

Weight In Kg	Experimental Voltage output In volt.	Experimental Current output In Am.	Experimental Power output In watt.	Simulation Result displacement in mm	Expected power output In watt	Relative Error %
5	5.3	0.151	0.8	28	1.03	28
10	12.3	0.163	1.97	68	2.5	26
18	19.1	0.201	3.81	130	4.8	25
20	21.6	0.203	4.38	146	5.4	23
30	27.6	0.241	6.65	225	8.3	24

## Electricity Generation from Hydraulic System Speed Breaker

Table A-5 Component used for the prototype and its specification

S. No.	Component Name	Quantity	Specification
1.	Motor:	1	(i)Type: D.C. Motor (ii)Voltage : 220 – 240 (iii) current ; 3.5 A
2.	Gear:	2	(i) No. of teeth : 76(big gear) (ii)No. of teeth : 24(small gear)
3.	Spring :	2	(i)Total displacement : 220 mm (ii) free length : 350 mm (iii) solid length : 130 mm (iv) wire diameter : 7 mm (v) No of turn : 9
4	Bearing	2	(i) Type: Rolling contact bearing (ii) Bearing no. N50
5	shaft	1	(i)Diameter : 35mm (ii) Length : 500mm
6	Cylinder	2	(i)large cylinder Di :128 mm (ii)large cylinder Do : 140 mm (iii)small cylinder Di :65mm (ii)large cylinder Do : 70 mm
7	Rack	1	(i)Length : 650 (ii) No of teeth : 26
8	pinion	1	(i)No of teeth : 16
9	frame	1	(i)length : 500mm (ii)width : 540mm (iii)depth : 320mm
10	Piston	2	(i)upper piston thickness : 35 mm (ii)lower piston thickness : 40 mm (iii)upper piston dia : 64 mm (iv)lower piston dia : 127 mm

