INVESTIGATION ON THE IMPACTS OF TRAFFIC ENERGY HARVESTER ON SPEED BREAKERS

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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Specially dedicated to
my beloved mother and father

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ABSTRACT

In recent years, over-dependency on non-renewable resources as power source has caused energy crisis. As the human population is increasing day by day and the non-renewable resources are diminishing, there is need for a solution to tackle this issue. Thus, various traffic energy harvesters had been proposed in many researches. However, these devices to harvest the traffic energy have low implementation across the country. This is due to the poor understanding and doubts on the implementation of these devices such as the possible impacts to the society. Thus, this project is carried out to study these impacts of traffic energy harvester on speed breakers and to clear those doubts. In this project, the speed breaker is utilized to generate electricity from the traffic energy as the vehicles travel across it. Traffic energy can be considered as renewable energy as it is available all year round but it will be wasted if it is left untapped. The rack and pinion mechanism is chosen to tap this energy and convert it to useful energy. The potential energy from the vehicle as it passes through the bump is converted into kinetic energy by this mechanism which is then used to rotate the rotor of generator and electricity is produced. The issue on the suitability of the mechanism to be implemented is discussed in this report.

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CHAPTER 1

INTRODUCTION

1.1 Background

In this modern era, our natural resources such as water, food, wood, natural gas, oil, and so on are slowly diminishing from our planet as we do not take the necessary counter measures to protect and prevent it from vanishing. Natural resources are essential for the survival of human kinds. They are the main sources of our daily needs. However, due to extensive usage of energy, these vast natural resources are being exploited to satisfy our needs which cause energy crisis. Thus, methods of optimal utilization are necessary in order to overcome the crisis and to conserve these natural resources. One of the best possible solutions is to reduce the dependencies on non-renewable resources like fossil fuels. Much of the industries are still powered by fossil fuels, but new technologies are evolving as the time goes on with the use of renewable energies such as solar, wind, water and so on. However, this isn't easy as many leading industries still uses fossil fuels as their primary power source for manufacturing.

Energy exists in many different forms such as light energy, heat energy, electrical energy, mechanical energy, nuclear energy and so on. One among these energies is traffic energy. Rather than being left untapped and wasted as heat energy, harvesting it would make a tremendous deal in combating the over-dependency on non-renewable energy, as traffic energy can be considered as a renewable energy. These forms of energy can be transferred and converted between one another. Energy can be divided into two major types which are potential energy and kinetic energy.

This project utilizes both the potential and kinetic energy through a commonly used system, the speed breaker. Energy tapped from this mechanism can be used to power up nearby electrical appliances such as street lamps. Among many proposed methods to implement this mechanism, the common methods used are rack and pinion mechanism, roller mechanism and crankshaft mechanism. When the load of the vehicles exerts force upon the speed breaker, the potential energy is converted into kinetic energy through various mechanisms where the motion is transferred into a generator to generate electricity.

1.2 Advantages

Traffic energy harvesting does not require consumption of fossil fuel as its source of power (potential energy from the vehicles when travel across the speed breaker) can be considered as a renewable energy. Thus, it is environmentally friendly. With zero consumption on fossil fuels, it helps in conserving the natural resources. In this mechanism, the source of power from the potential energy produced by vehicles on the bumper as it comes to a halt is converted to kinetic energy and then electrical energy by the mechanism in the speed breaker. This energy if left untapped will be wasted in the form of heat. Since this energy relies only on the vehicles and the mechanism itself, the energy is available all year round with no shortage of energy source.

Besides, this mechanism also has zero emission of greenhouse gases such as carbon dioxide, nitrogen oxide methane and other gases which are harmful to our environment because it mainly depends on the mechanical energy. Thus, it helps in combating against the global warming that results in climate change, rising of water levels and other natural impacts.

1.3 Problem Statements

Currently, the most advanced and efficient methods of power generation are from carbon related sources extracted from fossil fuels. In Malaysia, the existing power network is mostly operated on diesel and coals. Thus, an alternative source of power is needed to provide solution on the over-dependency of non-renewable resources which can harm our environment. A need of clean and environmentally friendly sources is vital in combating against the carbon related environmental impacts such as global warming. A combination of renewable energy and energy harvesting would provide a viable solution. Harvesting the energy from vehicles through speed breakers would contribute to the Malaysia's target of becoming carbon neutral.

However, there are doubts in our society on the practical implementation of traffic energy harvester. This is the main reason of the low implementation of traffic energy harvester devices across the world. Among many traffic energy harvester devices that have been proposed, this project emphasizes on the speed breaker as the mechanism to harvest the traffic energy. In order to implement the speed breaker as a power generation unit, impact study on this new mechanism is important. It is important to prove that it is has the potential to be developed in large scale, and prove its practicability and cost effectiveness in comparison to conventional speed breaker in order to clear the doubts on its effectiveness as a power generation unit. Thus, this project is to investigate the impacts of traffic energy harnessing system on speed breakers to determine its positive and negative impacts on our society. Through this project, the possible impacts on the power generation speed breaker are being researched. Based on these impacts, simulations on speed breaker mechanism are being conducted to show the effects of these impacts on real life situation.

1.4 Aims and Objectives

The aim of this project is to investigate the impacts of the traffic energy harvester on speed breakers. The impact study of the speed breaker power generation on the road and speed breaker itself is very critical in combating against the over-dependence of power generation from non-renewable resources. The objectives of this study are as follows:

1. To identify the possible impacts of the traffic energy harnessing system on speed breakers.
2. To identify a suitable design for the speed breaker and the harnessing mechanism.
3. To simulate the speed breaker and the harnessing mechanism using Autodesk Inventor.
4. To investigate the effect of material and numerical parameters, such as tensile strength, stresses and strain forces on the durability of the speed breaker.

1.5 Topic Outline

In this topic of Investigation on the Impacts of Traffic Energy Harvester on Speed Breakers**,** a speed breaker is used as an energy harvester mechanism. It uses the traffic energy as source of energy which is a renewable energy. The traffic energy is mainly comprises of mechanical energy which is potential energy and kinetic energy. However, there are doubts in our society on the practical implementation of traffic energy harvester. Therefore, the aim of this project is to investigate the impacts of the traffic energy harvester on speed breakers to prove its practicability in comparison to conventional speed breaker.

There are lots of researches being done on the design of energy harvesters for the speed breaker. However, there are none investigate on impacts of these traffic energy harvester on the speed breaker. Few mechanisms have been proposed as energy harvester for the speed breaker such as rack and pinion mechanism, crankshaft mechanism and roller mechanism. The literature review in this paper shows the comparison between these mechanisms. Among these mechanisms, rack and pinion mechanism is considered to be the best. The rack and pinion mechanism consists of mechanical components such as rack and pinion, gears, chain drives and others. There is also review on the possible impacts of the speed breaker with energy harvester on its surrounding.

For methodology part, firstly, the concept design for the speed breaker is being drafted based on the design of other researches in this mechanism. Then based on the design, the mechanical components of the speed breaker mechanism are being modelled. After the development of the mechanical components, they are integrated into a simulation model. A model of conventional speed breaker is also being modelled to make a comparison. Then, the models are simulated based on the material and numerical parameters on the response of the speed breakers.

As for results and discussions, the working principle of the design of rack and pinion is being determined based on the simulation of the models. Each of the components is being assigned with materials which have its own properties of yield and tensile strength. Then, stress analysis is used to simulate and analysed the models.

From the results, suitability of the design of the rack and pinion mechanism to be implemented is being determined. There are improvements and changes that can be done on the mechanism to improve its design. This mechanism has a great potential as it has many applications such as to power the traffic lights and street lights.

CHAPTER 2

LITERATURE REVIEW

2.1 Traffic Energy Harvesting

Energy harvesting is the process where the energy is harnessed from other sources like traffic energy which is unused and depleted, which is then converted to a more usable form. Energy harvesters provide power for low energy electronics in a very small amount. The source of energy for the energy harvesters is free without depleting the natural resources.

There are some researches on the traffic energy harvesting in the pavement engineering field. Andriopoulou (2012) had discussed on the technologies for traffic energy harvesting that have been studied such as asphalt solar collector combined with piping system, photovoltaic applications in the road infrastructure, embedded piezoelectric sensors and so on. For asphalt solar collector, the solar energy are being extracted and converted into thermal or electrical energy. The warmth of the asphalt pavement is captured by the water piping system and the energy is stored. As for the PV system, it is embedded into the pavement infrastructure. It captures the solar energy and converts it into electrical energy which is then being stored. Then, for the embedded piezoelectric sensors in the pavement infrastructure, it generates electrical voltage due to the alteration to its dimension when there are mechanical stresses.

However, in this paper, traffic harvesting through speed breaker is being introduced and studied. This is because this mechanism has a high energy efficiency and cost effective to be implemented.

2.2 Electricity Generation through Speed Breaker

There are different types of mechanism developed for generation of electricity from speed breaker. Among these, the popular ones are Rack and Pinion, Roller and Crankshaft mechanism. For Rack and Pinion and Crankshaft mechanism, basically, it involves weight from vehicles that exerted a force upon the speed breaker. The potential energy from the compression of the dome of the speed breaker is converted into kinetic energy through these mechanisms where the motion is transfer into a generator to generate electricity. In Roller mechanism, the friction force due to the vehicle movement acted upon the roller is then transmitted to chain sprocket arrangements where the rotary motion is then transfer into a generator for electricity generation.

2.2.1 Rack and Pinion Mechanism

Rack and pinion is used to convert between rotary and linear motion. Flat toothed part is the rack, while gear is the pinion. Whenever a car is travelled across the speed breaker, the dome is pressed downwards. The rack attached to the bottom of the dome will move downward which will rotates the pinion. Through multiple series of gear drives, the speed of the rotation of gear is multiplied to higher speed that is enough to power the generator. The electricity produced from the generator will be stored in a battery which will be used to power the street lamps.

In Aniket, Pratik and Atul (2013), rack and pinion mechanism is used to harness traffic energy. Through calculation, it is found that when a 300kg vehicle travelled over the speed breaker, a power of 7.3575W is generated for every second which is 10.5948kW of power for 24 hours. This power output is more than sufficient to power four street lamps during the night.

Similar mechanism of rack and pinion was used in Aswathaman and Priyadharshini (2011). Through their experiment investigation, it is found that a vehicle travelling over the speed breaker at different speeds and loads, will generate different voltages. As the speed of the vehicle increases at constant load, the voltage generated from the mechanism decreases. However, when the load of the vehicle increases which travelled at a constant speed across the speed breaker, the voltage generated by the mechanism increases.

Aravind, et al. (2015) makes some modifications to the conventional design of rack and pinion mechanism with shortened rack and removal of spur gears. It reduces the number of moving parts thus increasing the power generation and reducing the cost of investments.

Figure 2.1: (Padma, Kiran, Suresh, 2014. p. 550) Rack and Pinion Gear Arrangement

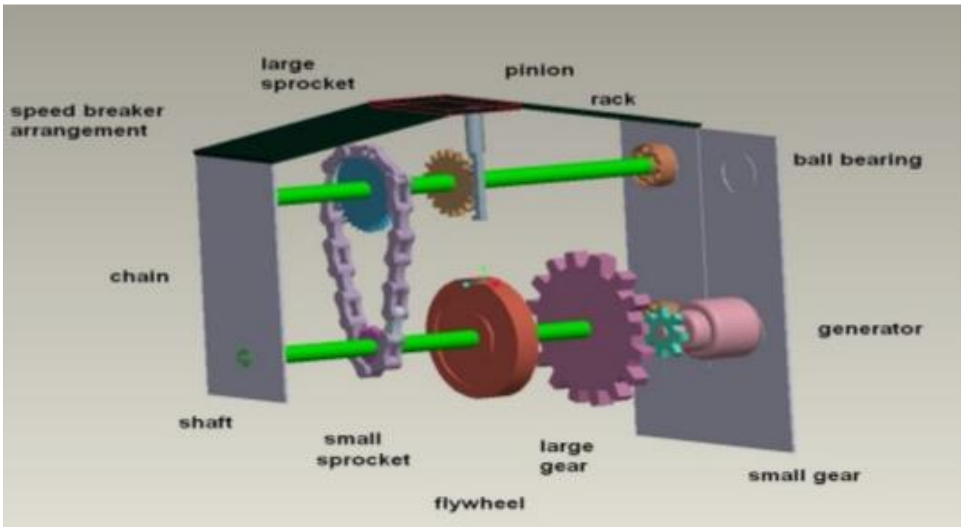


Figure 2.2: (Aniket, Pratik and Atul, 2013. p. 26) Rack and Pinion Model

2.2.2 Roller Mechanism

In this mechanism, rollers are fitted in between the speed breaker. The friction force due to the vehicle movement across the speed breaker acted upon the rollers and rotates them. 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 is produced.

Santhosh, Jyothi and Sudhir (2014) used roller mechanism for speed breaker power generation. In their investigation, it is found that the vehicle speed is inversely proportional to the voltage and current generated when the load of the vehicle is kept constant. However, the load of vehicle is directly proportional to the voltage and current generated when the speed of the vehicle travelling across the speed breaker is kept constant. Through calculation, it is found that the roller mechanism can generate a power of 1.67 W in a minute which is 2.3kW in 24 hours with a mass of vehicle of 205kg travelling across the speed breaker.

In Piyush, et al. (2014) has proposed model of the roller mechanism using Solidworks and analysed using ANSYS. The model was set up and experimented by a two-wheeler vehicle travelling across the model at different speeds to get the reading of voltage and current generated under different conditions. It can be seen that moving a small vehicle over the roller with its speed varies from 10-15 km/hour; the voltage produced is in the range of 3-4V.

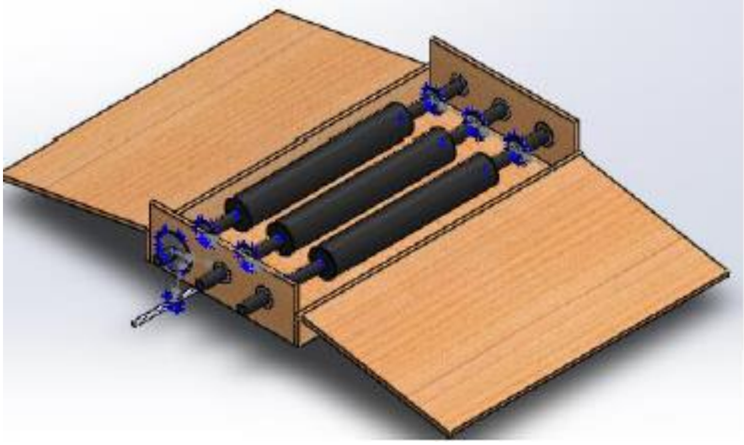


Figure 2.3: (Piyush, et al., 2014. p. 591) Roller Mechanism Model

2.2.3 Crankshaft Mechanism

The working principles of crankshaft mechanism is basically similar to that of rack and pinion mechanism which instead of using rack and pinion as its mechanical parts, it uses crankshaft. The linear motion of the dome of speed-breaker due to the compression of car is converted into rotary motion by the crankshaft. The crankshaft is then coupled with a larger gear. The large gear is meshed directly to a smaller gear which transmits the power of the larger gear to a smaller pinion. The speed at the larger gear is multiplied as the power is being transmitted to the smaller pinion. As the power is being 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.

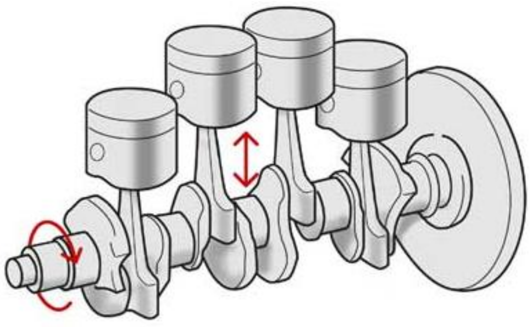


Figure 2.4: Crankshaft

Venkata, et al. (2014) calculated approximately 3.5MW of power output generated in 24 hours for its design of crankshaft mechanism.

2.2.4 Comparison between Different Mechanisms

Since there are a few mechanisms that are being proposed to be implemented in the speed breaker, comparison is being made to determine the most desirable mechanism. Zeeshan, Muhammad and Abubakr (2014) had made comparison between the three mechanisms which are rack and pinion mechanism, roller mechanism and crankshaft mechanism. Roller mechanism has a few disadvantages which are the difficulty in maintenance and might cause collision. For crankshaft mechanism, there are also a few disadvantages which are mechanical vibration that may cause damage to the bearings, the requirement of crankshaft to be mounted on bearings which can cause balancing problems, and variation of loads that also leads to balancing problem as bearings are of sliding type. As for rack and pinion mechanism, the paper had stated that it has a few advantages which it gives good mounting convenience, small maximum gear losses of 3 to 5% and high efficiency approximate to 95%. Thus, rack and pinion mechanism is found to be the most suitable to be implemented in the speed breaker to provide a more desirable output.

2.3 Durability of Speed Breaker Mechanism

With a new mechanism integrated in the speed breaker, it is of much important to determine that it is more beneficial than the conventional speed breaker so that it can be implemented. There are a few mechanisms being proposed which are rack and pinion, roller and crankshaft mechanisms. Since it is found that rack and pinion is the most desirable mechanism, the components used in this mechanism are being investigated to determine their durability. With a proper calculation and estimation of the load and speed of vehicle, the lifespan of the speed breaker could be known and thus maintenance is carried out whenever it is deem necessary. Thus, factors affecting the lifespan of the new speed breaker are being studied. Then, the parameters that affect the components in the mechanism of the speed breaker are being determined and researched.

2.3.1 Components in Rack and Pinion Mechanism

The main components that are used in rack and pinion mechanism are as follows:

1. Rack and pinion
2. Springs
3. Spur gears
4. Flywheel
5. Shaft
6. Generator

2.3.1.1 Rack and Pinion

Rack and pinion is a type of linear actuator which is used to convert between rotary and linear motion. The flat toothed part is the rack, while the pinion is the gear.

2.3.1.2 Springs

Spring is an elastic body that will be distorted when it is being compressed and recover its shape when it is not.

For spring, Valsange (2012) had concluded the factors that affect the spring are surface imperfection, spring geometry, material selection, design parameters and raw material defect.

2.3.1.3 Spur Gears

Spur gear is a cylinder with the teeth aligned parallel to the axis of rotation.

In Zeeshan, Muhammad and Abubakr (2014), the permissible working stress for gear is being calculated by determine the tangential load on teeth, dynamic and static load.

2.3.1.4 Flywheel

Flywheel is a heavy wheel located on the shaft to smooth out delivery of power from a motor to a machine. It reduces the fluctuation in the speed.

2.3.1.5 Shaft

A shaft is a rotating element that transmits rotary motion to the other element.

2.3.1.6 Generator

It is a mechanism that converts the mechanical energy into electrical energy according to the principle of Faraday's Law in which the flux lines are being cut to generate electromotive force.

2.3.2 Von Mises Stress

Von Mises stress is used to simulate and analysed the results of the speed breakers. Kurowski (2012) states that Von Mises stress is comprises of six multidirectional stress components in a three dimensional object. The Von Mises uses a uniaxial stress test to finds the stress applied on the material properties.

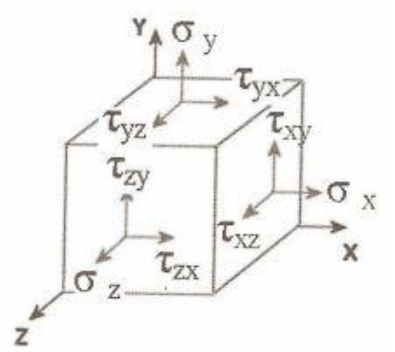


Figure 2.5: Six stress components of 3D

2.4 Impact of Speed Breaker on its Surrounding

Speed breaker is a traffic calming device in order to slow vehicle traffic to improve safety conditions. It is often associated with the relationship between the speed and crash risk of vehicles. This had been investigated by Elvik, et al. (2004 cited in Archer, et al., 2008, p.7) which has concluded that "The mean speed of traffic is the most important risk factor for road accident fatalities. It has a more powerful effect on road accident fatalities than any other known risk factor, including the overall amount of travel. Speed as a risk factor is always present. Many other risk factors, like darkness or a slippery road surface, are not always present." The new mechanism of the speed breaker is beneficial for generation of electricity, however, it also important that the speed breaker is built without compromising the safety of the road users.

2.4.1 Damage to the Road and Speed Breaker by Heavy Vehicles

Heavy loaded vehicles such as trucks can cause damages to the road and speed breakers. Roads Department (2000) explains that there is a direct pressure exerted by a truck on the contact area between its tires and the surface of the road. The intensity of the pressure is greatest at the surface of the road and spreads in a pyramidal shape through the thickness of the road structure and the soil beneath the road. As the contact area widens, the intensity decreases the pressure is low enough for the soil to support the load without deforming and causing damage to the road.

2.4.2 Fuel use and vehicle operating costs

In a report by OECD/ECMT (1996 cited in Archer, et al., 2008, p.32), the relationship of reducing vehicle speed and the fuel consumption had been investigated. According to the report, in France, 350,000 tons of oil (1.4%) were saved by car drivers if they fully comply with the speed limits. Similarity, in the

Netherlands, when there is a drop in average speed, there was a saving of 40 million liters of petrol. In 1996, in New Zealand, an increase in speed limits would increase the fuel consumption of vehicle by around 10% (Waring, 1996 cited in Archer, et al., 2008, p.32).

2.4.3 Emissions

Air pollutants like carbon dioxide, nitrogen oxides, particulate matter, methane and other harmful substances are emitted by motor vehicles into the environment. Air pollutants can contribute to air quality problems particularly in the urban area which can cause photochemical smog and detrimental effect on human health.

Indrajit (2015) had done an investigation on the relationship between the speed of the vehicle and the emission of the pollutants. It is found that there is no emission that is more than 5 gm/km from the passenger cars and heavy duty diesel vehicles when speed limit is less than 40 km/hour but it has a significant reduction in the emission when the speed limit had increased to more than 70km/hour at the traffic points in Kolkata. It had concluded that the reduction of the vehicle speed leads to the increase rate of emission of pollutants by the vehicle. Moreover, the increasing of the traffic speed reduces the emission from vehicles which are fuelled by gasoline and diesel.

2.4.4 Energy Efficiency

Climate change due to global warming is happening and is caused by the release of greenhouse gas emissions from the increasing of human activities due to the burning of oil and gas for energy. Thus energy efficiency plays an important role in countering the issues. Energy efficiency means using less energy input to provide the same energy output.

So, the new mechanism implemented in the speed breaker has higher energy efficiency as compared to the conventional speed breaker. This is because rather than the traffic energy being left untapped and wasted, the new speed breaker mechanism converts this energy into electrical energy. Although the application is quite small, but with a huge implementation of this mechanism in every speed breakers, there will be a huge impact on the over-dependence of non-renewable resources to generate that amount of electricity.

2.5 Conclusion

Many researches have been conducted on various traffic energy harvesters. However in this project, speed breaker is chosen as the mechanism to harvest the traffic energy. In this chapter, the investigation on the possible impacts of the energy harvester on the speed breaker mechanism is being carried out. This is to clear the doubts of many people on the practicability of implementing the speed breaker as a power generation unit. From various speed breaker mechanisms such as rack and pinion, roller, crankshaft and so on, that had been proposed, rack and pinion is found to be better than the other mechanisms due to its high efficiency and small losses.

CHAPTER 3

METHODOLOGY

3.1 Overview

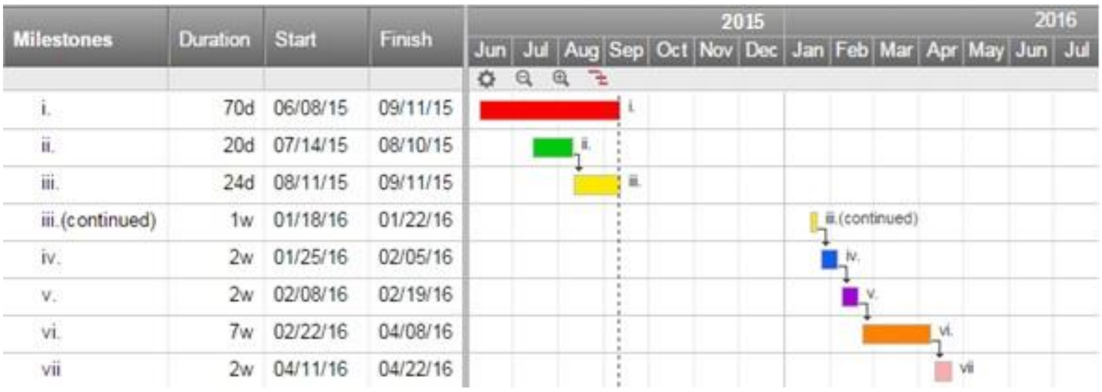
The scope of this project is to study the impact of speed breaker power generation on the road or speed breaker. The report focuses on rack and pinion mechanism in order to generate electricity from the speed breaker. With a proper estimation and calculation of the load and speed of the vehicle, the force exerted on the speed breaker can be determined. Then, calculation and selections of the main components such as rack and pinion, gear drives and springs were made to design this mechanism. The issue on the durability of the mechanism is also included in this report. The purpose of this work is to clear the doubts of the society on the effectiveness of implementing the speed breaker as a power generation unit.

To achieve the aims and objectives of project, there are several steps involved which are the following subsections of this chapter. The following are the milestones to be achieved in this project:

i. Literature review
ii. Concept design for speed breaker mechanism
iii. Modeling of mechanical components of the speed breaker mechanism
iv. Development of simulation model of a conventional speed breaker
v. Development of simulation model of a speed breaker with energy harvester
vi. Simulation of the material and numerical parameters, such as tensile strength, stresses and strain forces on the response of the speed breakers
vii. Documentation

The following are the Gantt chart for this project:

Table 3.1: Gantt Chart for the whole project



Milestones	Duration	Start	Finish
i.	70d	06/08/15	09/11/15
ii.	20d	07/14/15	08/10/15
iii.	24d	08/11/15	09/11/15
iii.(continued)	1w	01/18/16	01/22/16
iv.	2w	01/25/16	02/05/16
v.	2w	02/08/16	02/19/16
vi.	7w	02/22/16	04/08/16
vii	2w	04/11/16	04/22/16

3.2 Literature Review

The possible impacts of the traffic energy harvesting system on speed breakers had been listed out in the Chapter 2 of this project.

3.3 Concept design of the speed breaker mechanism

The rack and pinion mechanism for speed breaker will have the following functions:

1. The bump of the speed breaker is lifted to a certain height from the surface of the road.

2. Then there will be springs beneath the speed breaker. The potential energy from vehicles will compressed the springs via the bump. The spring should be resilient so that it can expand to its original length for the next compression.

3. A rack is attached underneath the bump to relay the linear motion (vertically) to rotary motion of the pinion which is coupled to it. This will rotate the shaft of the generator to produce electricity.

4. The rotation is multiplied by using certain mechanism, like gears and chain drive, in between the relay motion of pinion to the generator. Therefore, a small compression from the vehicle will be able to produce sufficient power to charge a battery due to the increased of rotations in the mechanism.

5. The electricity generated will then be stored in batteries during the day time and the power generated will be used to power the street lights during night time or rainy day.

The speed breaker mechanism is supported by springs. When a vehicle mounts the speed breaker, the load on the bump compresses the springs which causes a linear motion and converted to a rotary motion through a rack and pinion mechanism. The energy is generated and can be stored in batteries. The input to generate electricity is the weight of the vehicle.

The power generated by the cars as they travelled across the speed breaker mechanism was calculated using the formulas shown below. The force exerted by the car upon the dome of speed breaker is as follow,

$$Force = mass \times gravitational\ acceleration \tag{3.1}$$

For the calculation of vehicle weight which is the force exerted in Newton (N), the weight which would or may be incorporated in real life was ignored. The mass is the mass of the car in kg. The value of gravitational acceleration is 9.8 m/s^2. Thus, the output power is calculated with the equation,

$$Output\ Power\ (W) = \frac{Force\ (N) \times Height\ of\ the\ speed\ breaker\ (m)}{60\ (seconds)} \tag{3.2}$$

The output power is the power that is generated by the generator of the mechanism. For the height of the speed breaker, it is the distance travelled by the dome of the speed breaker when it is being compressed by the weight of the car.

3.4 Modelling of mechanical components of the speed breaker mechanism

The main components that are used in rack and pinion mechanism are as follows:

1. Rack and pinion
2. Springs
3. Spur gears
4. Flywheel
5. Shaft
6. Generator

However, only a selected few are considered in the design calculation.

3.4.1 Helical Spring Design

The helical spring is shown in Figure 3.1 below under a load, F.

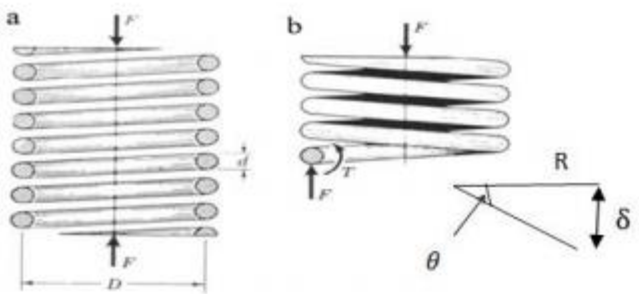


Figure 3.1: Schematic diagram of helical spring under load

Consider a helical spring under a load, F, Where, D is Diameter of coil, d is diameter of the coil wire, R is Radius of Coil, δ is Deflection of the coil under load, C is the Modulus of Rigidity of the Spring Material, n is the Number of coils or turns, θ is the Angle of Twist, l is the Length of wire = 2πRn, τ is the Shear Stress.

From Hooke's Law,

$$F = k\delta \tag{3.3}$$

Calculating the minimum deflection, δ of 0.01 m and applying force F as calculated above,

$$k = \frac{F}{\delta} \tag{3.4}$$

Also Allowable Stress for mild steel σ_{all} = 140MPa.

Force acting on spring, $F_A = F_B$.

Cross sectional area of spring,

$$A = \frac{F_A}{\sigma_{all}} = \frac{\pi d^2}{4} \tag{3.5}$$

Minimum spring wire diameter,

$$d = \sqrt{\frac{4F_A}{\pi\sigma_{all}}} \tag{3.6}$$

Also the minimum deflection as a result of load

$$\delta = \frac{64FR^3}{Cd^4} \tag{3.7}$$

Making the minimum mean radius subject of the formula

$$R = \sqrt[3]{\frac{\delta \times Cd^4}{64F}} \tag{3.8}$$

But mean diameter of spring, D

$$D = 2R \tag{3.9}$$

$$n = \frac{Cd^4}{64FR^3k} \tag{3.10}$$

where,

k = 10

The Length of the wire

$$L = 2\pi Rn \tag{3.11}$$

3.4.2 Rack and Pinion

Parameters involved:

$$\text{Module} = \text{Pitch Circle Diameter(D)} / \text{No. of teeth(N)} \qquad (3.12)$$

Radius of Pitch Circle (r)

Addendum (a) = module

$$\text{Circle radius of addendum (ra)} = r + a \qquad (3.13)$$

Pressure angle of pinion (Φ)

$$\text{Length of path of contact} = (a / \sin \Phi) + \{ [ra \hat{}2 - (r \sin \Phi) \hat{}2]\} \hat{}0.5 - r \sin \Phi \text{ mm} \qquad (3.14)$$

$$\text{Length of arc of contact} = \text{Length of path of contact} / \sin \Phi \qquad (3.15)$$

$$\text{Minimum number of teeth in contact} = \text{Length of arc of contact} / \pi m \qquad (3.16)$$

$$\text{Angle turned by the pinion} = \text{Length of arc of contact} \times 360 / 2\pi ra \qquad (3.17)$$

$$\text{Minimum Length of rack} = 2\pi ra \qquad (3.18)$$

3.4.3 Design of Gears

Parameters and some calculations involved in Gear designing are as follows:

Outside Diameter (Do)

Number of Teeth (N)

$$\text{Pitch Circle Diameter } (D) = Do \,/\, (1 + 2/N) \qquad (3.19)$$

Module = D/N

Pressure angle of gear (Φ)

$$\text{Diametric Pitch (P)} = N / D \qquad (3.20)$$

$$\text{Addendum (a)} = 1 / P \tag{3.21}$$

$$\text{Addendum (b)} = 1.157 / P \tag{3.22}$$

$$\text{Tooth Thickness} = 1.5708 / P \tag{3.23}$$

$$\text{Whole Depth} = 2.157 / P \tag{3.24}$$

$$\text{Clearance} = 0.157 / P \tag{3.25}$$

$$\text{Centre Distance} = (N1 + N2) / (2P) \tag{3.26}$$

$$\text{Working Depth} = \frac{2}{P} \tag{3.27}$$

$$\text{Addendum Circle Diameter} = D + 2m \tag{3.28}$$

$$\text{Dedendum Circle Diameter} = D - 2.5m \tag{3.29}$$

3.5 Development of model of a conventional speed breaker

Autodesk Inventor will be used to model the traditional speed breaker. With the model being built, the dynamic behaviour of the system is simulated. The result of it will be used for analysis.

3.6 Development of model of a speed breaker with energy harvester

The model of a speed breaker with energy harvester is built using Autodesk Inventor. There will be mechanical components of rack and pinion mechanism being integrated into the design of speed breaker. This is to simulate the dynamic behavior of the system. It is then compare with the simulation of the conventional speed breaker.

3.7 Simulation of the material and numerical parameters, such as tensile strength, stresses and strain forces on the response of the speed breakers

In designing the rack and pinion mechanism of speed breaker, proper selection of material for the components and also the structure are the key to achieve a design which is durable, sustainable and reliable. So, it is important to determine the properties of materials for the design. The selection of material depends on the following factors.

1. Availability of the materials.
2. Suitability of materials for working condition.
3. The cost of materials.
4. Physical and chemical properties of material.
5. Mechanical properties of material.

The mechanical properties are associated with the ability of the material to resist mechanical forces and load. Required properties for the selection of material are Strength, stress, stiffness, elasticity, plasticity, ductility, brittleness, toughness, resilience, creep, hardness. In designing the various part of the machine it is necessary to know how the material will function in service. For this certain characteristics or mechanical properties mostly used in mechanical engineering practice are commonly determined from standard tensile tests.

The selection of the materials depends upon the various types of stresses that are set up during operation. The material selected should withstand it. The following Table 3.2 shows the material assigned to components in the design of rack and pinion mechanism.

Material used:

Table 3.2: Material for each component

Parts	Material
Bump	Concrete
Wall	Steel
Springs	Stainless Steel
Rack	Stainless Steel
Pinion	Stainless Steel
Shafts	Stainless Steel
Sprockets	Stainless Steel
Chain	Stainless Steel
Flywheel	Stainless Steel
Spur Gears	Stainless Steel

In this project, the Stress Analysis in Autodesk Inventor will be used to determine the suitability of the materials of the speed breaker mechanism. It is used to predict the response of the speed breaker mechanism by the influence of the forces and torques. The results from the analysis show whether the product will maintain its conditions the way it was designed.

Thus, with the help of this simulation, the factors that affect the condition or quality of the mechanism can be determined. The components in the speed breaker mechanism will be simulated and the impacts on the speed breaker will be tested and determined.

3.8 Documentation

This project is documented into a report after results and discussion of the simulations.

3.9 Conclusion

The process in order to obtain the results is important so that correct and detailed simulation and analysis is achievable to get accurate data. This chapter shows the steps or methods involved in order to obtain the results of the simulations of the speed breakers. With the modelling of the speed breakers based on the design, simulation and analysis could be done using Autodesk Inventor.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results of the simulation and the stress analysis of the speed breaker are shown and discussed. There will be comparison between the simulation of the speed breaker with energy harvester and the conventional speed breaker. Throughout this chapter, the suitability of the speed breaker with energy harvester to be implemented is investigated. The results and analysis from the simulations are used to determine whether there is a need of improvement or changes to be done to the design.

4.2 Modelling

There are lot of existing papers and researches for the design of the speed breaker with energy harvester using the rack and pinion mechanism. So, in this paper, the modelling of the speed breaker with rack and pinion mechanism is attained from those papers and integrated it into the model. The proposed model of rack and pinion mechanism for speed breaker has been modelled using Autodesk Inventor and analysed using the stress analysis.

The mechanism comprises of bump, wall and mechanical components. The base of the speed breaker is 1000 × 500 mm. The wall is used to support the shafts and the structure. Figure 4.1 and Figure 4.2 show the complete assembly of the mechanism. Three shafts of 1000 mm in length and 50 mm diameter are fitted between the two sides of the wall. The shafts can be clearly seen in Figure 4.2. The shafts are mounted with mechanical components and also used to relay the rotational motion to the other components. The rack of 9 teeth with base of 40 × 50 mm and height of 290 mm is attached to the bump. It is connected with a pinion of 12 teeth with 100 mm pitch diameter and 120mm outer diameter. The pinion is in turn connected to the chain drive via a shaft. The chain drive consists of two sprockets of 24 teeth and 17 teeth respectively with 24 teeth sprocket mounted on the same shaft with the pinion but the 17 teeth sprocket is mounted on the second shaft. The sprockets are connected via chains so as to give them uniform rotation. The 17 teeth sprocket is mounted on the same shaft with a flywheel and a large gear. The flywheel has a diameter of 176 mm while the large gear has a diameter of 210 mm with 40 teeth. The large gear is then coupled with a small gear of 130 mm diameter with 24 teeth which is mounted on the third shaft. There are 4 springs attached between the bump and the wall where each of them is located at the corners.

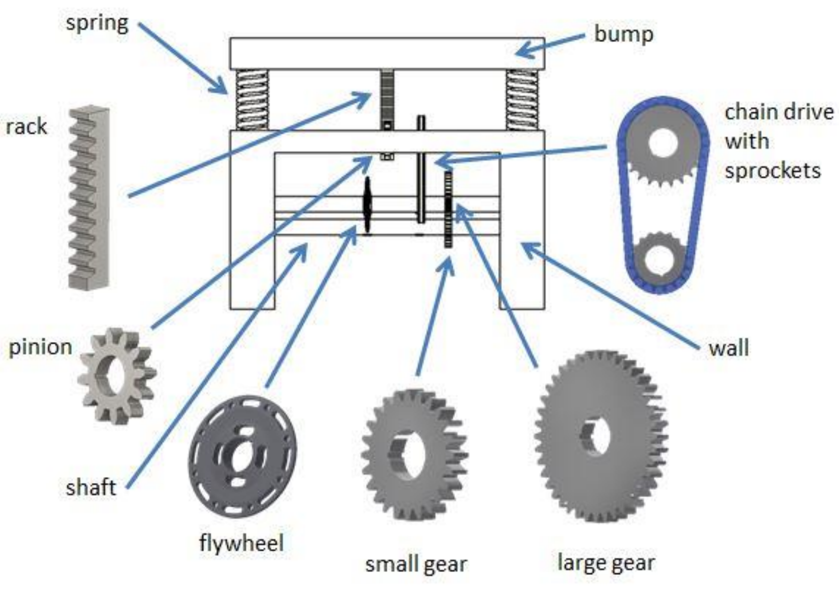


Figure 4.1: Components of speed breaker with energy harvester

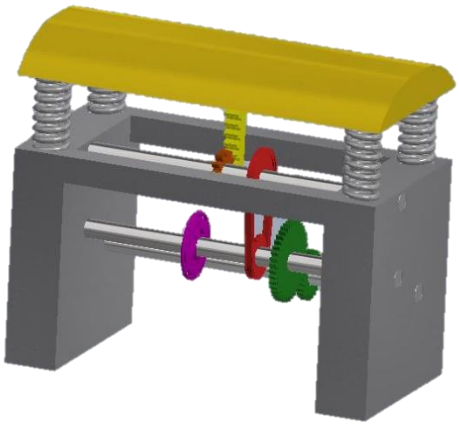


Figure 4.2: Simulation model

4.3 Working Principle

Rack and pinion is used to convert between linear and rotary motion. Whenever a car is travels across the speed breaker, the bump is pressed downwards. The rack attached to the bottom of the bump will move downward which will rotate the pinion. The pinion will then rotate the larger sprocket of the chain drive via the shaft. The motion of the chain drive will then rotate the smaller sprocket which eventually drives the large gear mounted on the same shaft. The large gear will then rotate the smaller gear which is connected to it. Through multiple series of gear drives as shown in Figure 4.1 and 4.2, the speed of the rotation of gear is multiplied to higher speed that is enough to power the generator (not shown in the figures as it does not contribute to the analysis).

4.4 Constructional Material(s)

Autodesk Inventor provided the Material library which is a collection of material definitions being defined with its physical properties. The physical properties provide information on the material composition that will be used for simulation and analysis. Appropriate material can be assigned to the objects or parts of the design. The following Table 4.1, 4.2 and 4.3 show the type of materials available in Autodesk Inventor's Material library being assigned to parts of the speed breaker with energy harvester and conventional speed breaker together with their information:

Table 4.1: Properties of concrete

Part Name(s)	Bump	
Material	Concrete	
General	Mass Density	2.40731 g/cm^3
	Yield Strength	2.41329 MPa
	Ultimate Tensile Strength	2.41329 MPa
Stress	Young's Modulus	23.25 GPa
	Poisson's Ratio	0.167 ul
	Shear Modulus	9.96144 GPa

Table 4.2: Properties of Steel

Part Name(s)	wall	
Material	Steel, High Strength, Low Alloy	
General	Mass Density	7.85 g/cm^3
	Yield Strength	275.8 MPa
	Ultimate Tensile Strength	448 MPa
Stress	Young's Modulus	200 GPa
	Poisson's Ratio	0.287 ul
	Shear Modulus	77.7001 GPa

Table 4.3: Properties of stainless steel

Part Name(s)	pinion rack Flywheel shafts Roller Chain Roller Chain Sprocket1 Roller Chain Sprocket2 Spur Gear1 Spur Gear2 springs	
Material	Stainless Steel	
General	Mass Density	8 g/cm^3
	Yield Strength	250 MPa
	Ultimate Tensile Strength	540 MPa
Stress	Young's Modulus	193 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	74.2308 GPa

Yield strength is defined as the stress at which a material begins to deform plastically. When the stress applied reaches to the yield strength of the material, it will deform elastically and will return to its original shape when the applied stress is removed.

Tensile strength is a measurement of the force required to pull something or an object to the point where it breaks. The tensile strength of a material is the maximum amount of tensile stress that it can take before failure, for example breaking.

In this design, it is better for the material to have a high yield strength and also high tensile strength so that the stress applied to it will not permanently deform. Thus, it will need a very high stress to cause deformation to the material.

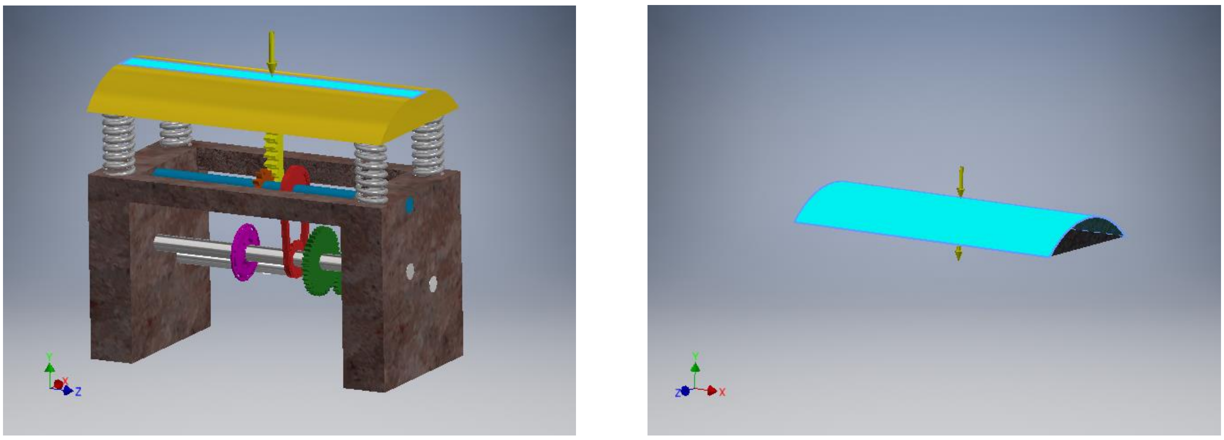
4.5 Stress Analysis

Stress analysis is used to simulate the response of the design when a stressed is applied. To imitate a real life situation, forces are added to the design to study its response. In this project, the force exerted by a car on the bump is assumed to be 20000 N. The input forces in Table 4.4 are forces that are actually being exerted on the parts being specified in Figure 4.3.

Constraints are also added to mimic environmental conditions. Fixed constraints in Figure 4.4 are applied to establish grounded effect where there is zero displacement of the parts specified.

Table 4.4: A force of 20000N which is the average weight of a car is applied on the selected faces

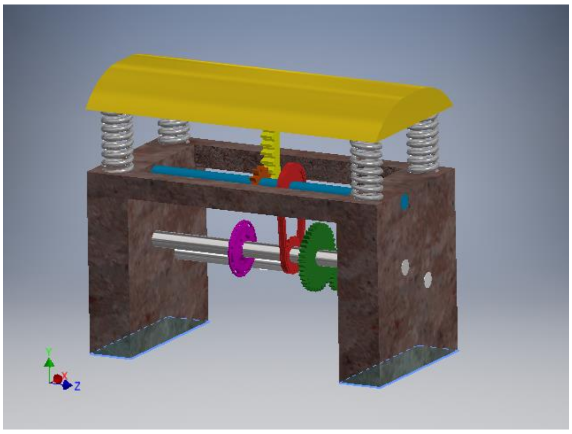
Load Type	Force
Magnitude	20000.000 N
Vector X	0.000 N
Vector Y	-20000.000 N
Vector Z	0.000 N



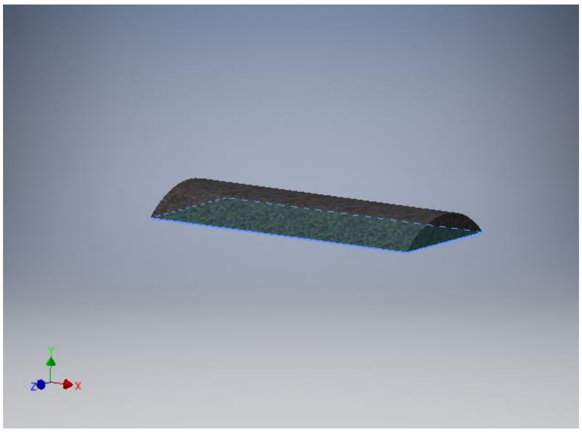
Selected face(s) for Speed Breaker with energy harvester

Selected face(s) for conventional speed breaker

Figure 4.3: Selected face(s) subjected to forces



Selected face(s) for Speed Breaker with energy harvester



Selected face(s) for conventional speed breaker

Figure 4.4: Selected face(s) subjected to constraints

Table 4.5: Summary of results for speed breaker with energy harvester

Name	Minimum	Maximum
Volume	132177000 mm^3	
Mass	836.409 kg	
Von Mises Stress	0.000047277 MPa	825.391 MPa
Displacement	0 mm	28.1421 mm
Safety Factor	0.302887 ul	15 ul
Stress XX	-479.13 MPa	486.891 MPa
Stress XY	-335.91 MPa	336.023 MPa
Stress XZ	-278.384 MPa	270.029 MPa
Stress YY	-913.454 MPa	698.774 MPa
Stress YZ	-352.036 MPa	369.899 MPa
Stress ZZ	-571.661 MPa	274.627 MPa
X Displacement	-0.458567 mm	2.24556 mm
Y Displacement	-28.1267 mm	0.0456566 mm
Z Displacement	-0.923634 mm	0.890982 mm
Equivalent Strain	0.00000000234032 ul	0.00384275 ul

Table 4.6: Summary of results for conventional speed breaker

Name	Minimum	Maximum
Volume	34376800 mm^3	
Mass	82.7558 kg	
Von Mises Stress	0.0295224 MPa	0.0480435 MPa
Displacement	0 mm	0.000170465 mm
Safety Factor	15 ul	15 ul
Stress XX	-0.0108113 MPa	0.00294729 MPa
Stress XY	-0.0070022 MPa	0.00699455 MPa
Stress XZ	-0.0012459 MPa	0.00128585 MPa
Stress YY	-0.0553184 MPa	-0.0343404 MPa
Stress YZ	-0.00548913 MPa	0.00740543 MPa
Stress ZZ	-0.0106217 MPa	-0.0016883 MPa
X Displacement	-0.0000415742 mm	0.0000416568 mm
Y Displacement	-0.00016512 mm	0 mm
Z Displacement	-0.0000162248 mm	0.0000257104 mm
Equivalent Strain	0.00000120912 ul	0.0000018945 ul

4.5.1 Von Mises Stress and Strain

The Von Mises stress is computed by Autodesk Inventor. A material is said to yield when its Von Mises stress reaches a critical value known as the yield strength. The Von Mises stress is used to predict yielding of materials under any loading condition from results of simple uniaxial tensile tests.

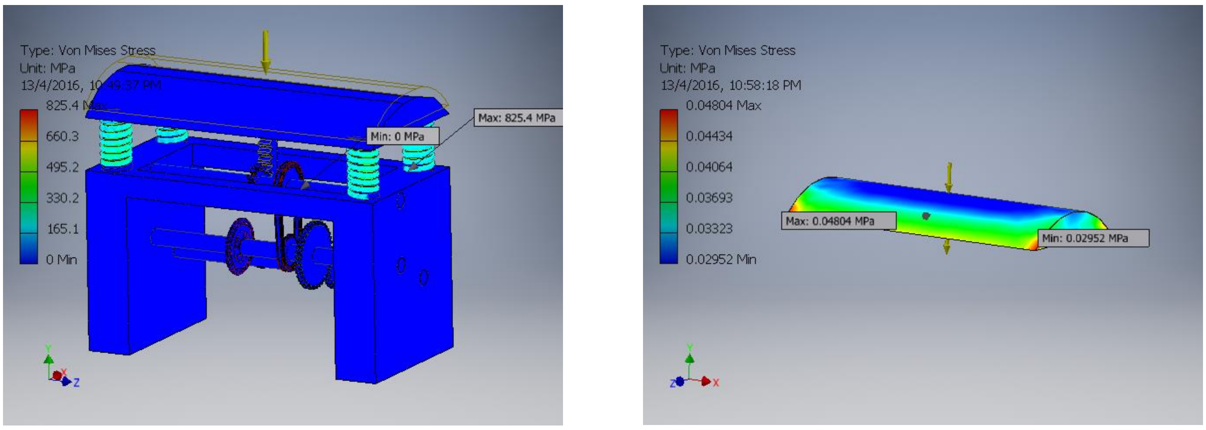
Strain is the response of a system to an applied stress. When a material is loaded with a force, it produces a stress, which then causes a material to deform. Engineering strain is defined as the amount of deformation in the direction of the applied force divided by the initial length of the material.

The Autodesk Inventor uses the Von Mises Stress to compute and simulate the results. The colour contours in both Figure 4.5 and 4.6 indicate the stress and strain being applied with red as the highest value and blue the lowest value. A force of 20000N is being applied on the surface of the bump. Both Figures for Von Mises stress and strain respectively showed the same colour distribution of speed breaker with energy harvester for the conventional speed breaker.

For the colour distribution across the speed breaker with energy harvester, it is almost covered with blue with the springs in aqua and some red underneath the spring which is hidden away. The maximum value for Von Mises stress is 825.4 MPa and minimum value is 0 MPa.

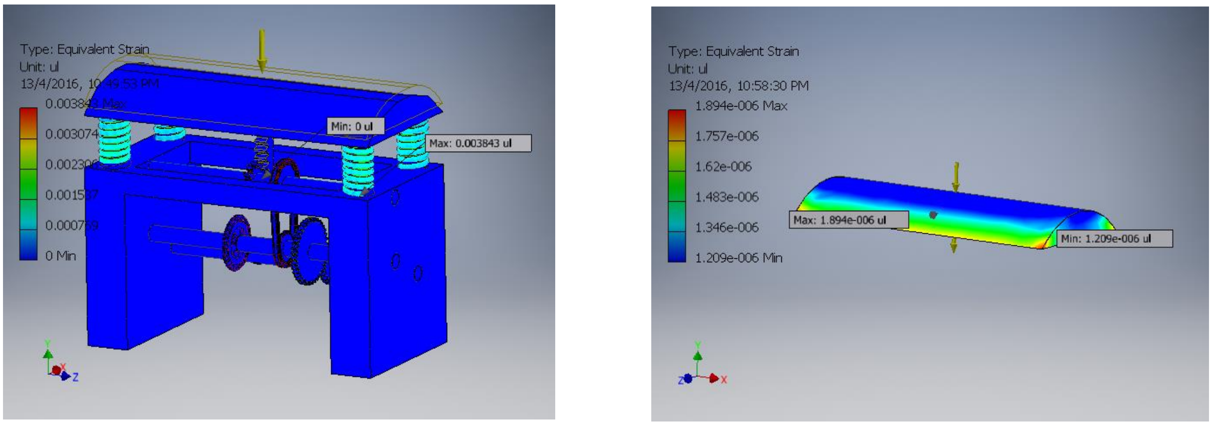
For conventional speed breaker, there is wide range of colours with the bottom corner slightly covered with red. The maximum value for Von Mises stress is 0.04804 MPa and minimum value of 0.02952 MPa.

These values are being compared with their own yield strength and tensile strength of the materials used in Table 4.1, 4.2 and 4.3. Therefore, both speed breakers are able to withstand the stress very well as their Von Mises Stress are way below the yield and tensile strength of the materials.



Speed breaker with energy harvester — Conventional speed breaker

Figure 4.5: Von Mises Stress



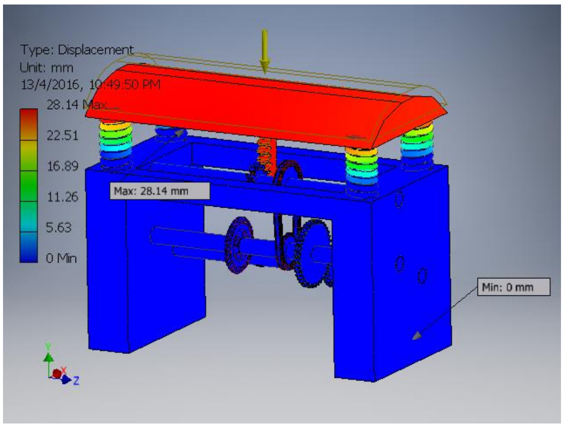
Speed breaker with energy harvester   Conventional speed breaker

Figure 4.6: Strain

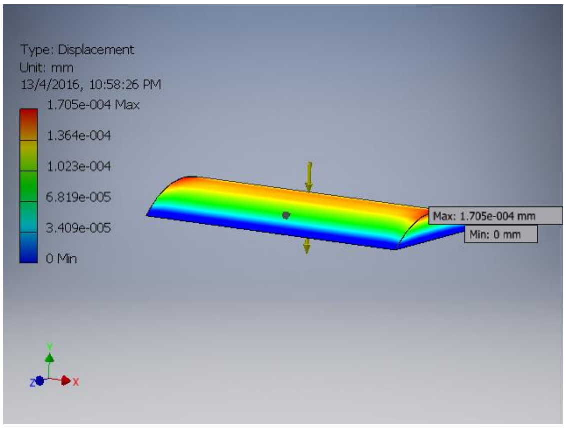
4.5.2 Displacement

The displacement shows how much the components are being displaced from their own position. The colour contour shows the blue colour being the minimum value and red colour being the maximum value of displacement.

The results show that the bump of the speed breaker with energy harvester is being displaced by nearly 30 mm while there is approximately 0 mm displacement for the conventional speed breaker when a force of 20000 N is applied. This shows that for the speed breaker with energy harvester, the springs are being compressed by 30 mm when a normal car is passed by. As for the conventional speed breaker, there should be no displacement as the whole structure is made from concrete with high yield and tensile strength.



Speed breaker with energy harvester



Conventional speed breaker

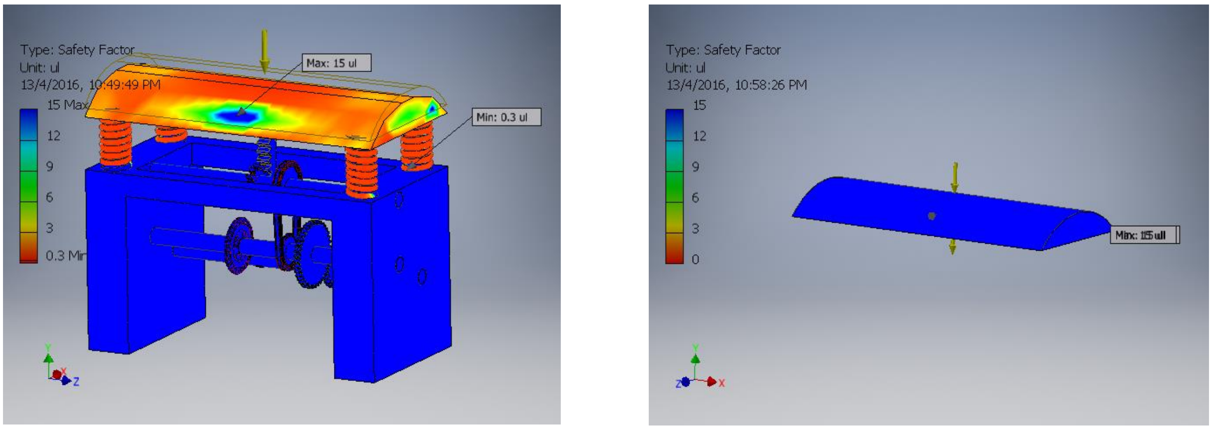
Figure 4.7: Displacement

4.5.3 Safety Factor

All objects are subjected to stress limits which can be represented by their yield or ultimate strengths. These objects will experience deformation if a stress above this limit is being applied. So, for a design which is not supposed to permanently deform, a maximum allowable stress should be less than the material yield strength.

In Autodesk Inventor, the safety factor is the ratio of maximum allowable stress to the Von Mises Stress. The ratio must be more than 1 for the design to be acceptable. Anything less than 1 means there are some deformation. In the simulation, the safety factor will indicate the areas of potential yield. The colour contour in Figure 4.8 shows a range of colours to indicate the value of safety factor. Red colour indicates the minimum safety factor of 0 and blue colour with maximum safety factor of 15.

Based on the simulation of safety factor in Figure 4.8, the safety factor for conventional speed breaker is more than 1. This means that it will not suffer any deformation. However, for the speed breaker with energy harvester, it can be seen in Figure 4.8 that there are areas with safety factor below 1 which are reddish in colour with the minimum value of safety factor is 0.3 located underneath the spring. This means that the spring and also some areas of the bump having a safety factor of less than 1 will suffer some deformation over a period of time. Thus, the material of the bump and spring should be changed so that their physical properties will have higher yield strength.



Speed breaker with energy harvester Conventional speed breaker

Figure 4.8: Safety Factor

4.6 Conclusion

Overall, the speed breaker with energy harvester which is designed in this project is not safe to be implemented based on the result of the safety factor. However, only the material of the bump and springs are needed to be changed so that their physical properties are strong enough to withstand the stress and have high yield strength. It can be seen that, there are no problems with the other components of the design as they can withstand the Von Mises Stress and have safety factor of more than 1. Thus, the speed breaker with energy harvester can be implemented once the material of the suggested parts are changed which could result in safety factor of more than 1.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The utilization of energy proves that we are concerning on the current issues and still fighting for a better future for the next generation. This project utilizes the traffic energy which if untapped, will be wasted as heat energy. Rack and pinion mechanism for harvesting the traffic energy through speed breaker was proposed. It generates electrical energy that is proportional to the density of vehicles passing through it. With the impacts study and simulation in this project, we can clear the doubts of our society on the practicability of implementing the speed breaker as a traffic energy harvester to provide electricity. As the impacts of the traffic energy harvester on the speed breakers had been investigated, we can determine the suitability of the power generation speed breaker to be implemented in large scale. Through this project, it is found that the design of the speed breaker with rack and pinion mechanism is insufficient to be implemented on the road. There are great needs for the improvement and changes in the design so that it is suitable to be implemented.

5.2 Recommendations

In engineering design, it is important to consider the following factors for a good design:

- Cost
- Safety
- Reliability
- Availability of material
- Durability
- Energy efficiency

So in this project, there are a few recommendations suggested to improve the design of the rack and pinion mechanism for speed breaker.

1. Bump

The bump that is used in the design is made of concrete. Although it provides a high yield and tensile strength, it is also heavy. It is better to use material which have similar properties but also light for the bump. There are bump which are made from rubber and ABS plastic available in the market. Thus, with a more lightweight material for the bump, the mechanism is more reliable and durable.

2. Spring

Springs need to be resilient, even when going through numerous compressions and deflections. A key component to this resiliency is in the spring material. The choice of material is based on numerous factors ranging from fatigue strength, cost and availability, corrosion resistance, magnetic permeability and even electrical conductivity.

3. Ball bearings

The design in this project can be further improve by adding ball bearings to the shaft. A roller-element bearing is a bearing which carries a load by placing round elements between the two pieces. The relative motion of the pieces causes the round elements to roll (tumble) with little sliding. They reduce the friction and transmit the motion effectively.

4. Safety

For safety purposes, the rack and pinion mechanism as energy harvester for the speed breaker should be installed at one lane of the road instead of the width of the road. This is to avoid the compression of the bump to affect the vehicles on the other lane.

5.3 Applications

Power generation with speed breaker can be used in most of the places such as:

- Housing area
- School area
- Toll Plaza
- Parking Lot
- Traffic Signals

The generated power from the speed breaker is stored in the battery. It can be used for:

i. Street Lights

A street light which is turned on or lit at a certain time every night. Modern lamps may also have light-sensitive photocells to turn them on at dusk, off at dawn, or activate automatically in dark weather.

ii. Traffic Lights

Traffic lights are signalling devices positioned at road intersections, pedestrian crossings and other locations to control competing flows of traffic.

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