Design and Fabrication of an Electric Power Generator Prototype: The Road as a Source of Clean Energy

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Abstract—*The demand for energy has greatly increased. The current sources of clean energy are not able to supply enough amount of energy. Consequently, Fossil fuels are still highly used in many countries. These are harmful to the environment. In addition, their sources are being depleted with time. Therefore, there is need to explore new sources of clean energy to solve this problem. In our project, we have designed a machine that can generate electricity from the energy of moving vehicles. We have introduced a new setup to of mechanical motion rectifier MMR. It has been shown that, a rack system that utilize both the downward and upward motion to drive a pinion increase the rotation time of a generator by 89.2% compared to devices that utilize the downward motion only. We have achieved peak power output ranging from 6.268W to 7.596W when masses from 26Kg to 40Kg were placed on the speed bump. This study gives useful information that will contribute to the future studies of similar devices and clean energy production.*

KEYWORDS

Energy, Flywheel, Gears, Power generation, Rack, Pinion

1. INTRODUCTION

Electrical energy demand in the world has increased [1].The increasing demand has led to the straining of the current energy sources.[1] The main sources of clean energy have not been able to supply the required amount of energy hence fossil fuels have remained a major source of energy; many people are still using them leading to environmental pollution. Thus, there is need to find new ways of generating clean energy to supplement the already available electric power.

Speed breaker Power Generator (SBPG) is an emerging technique that can utilize the energy possessed by moving vehicles to produce electrical energy. As vehicles run over speed bumps, they are compelled to rise to a given height. This increases their gravitational potential energy. For instance, a car of 1000kg going over speed bumps 10cm high gains a gravitational potential energy of about 1000Joules (1kJ). This energy can be tapped and converted into useful energy. It has been shown that SBPG can produce peak power up to 1kW [2].

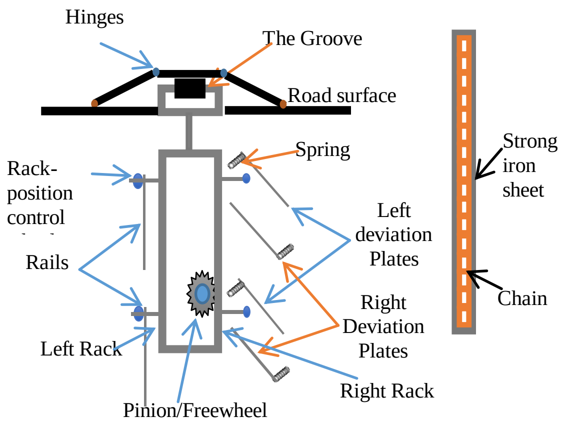
Several researchers have proposed different techniques of harnessing this wasted energy. These includes, among others, Hydraulic[3]–[5], Air Compression[6]–[9],Magnetic[9], Roller Mechanism [12], [13], Crank-Shaft Mechanism[14]–[16], and Rack-Pinion Mechanism[2], [10], [17]–[28]

A rack and pinion arrangement that utilizes both downward and upward motion of the rack, the mechanical motion rectifier (MMR), has been designed [22]. These researchers used two pinions that are driven by one rack. Other researchers have used two sets of racks and two pinions[2], [24]. It has been shown that this approach is able to increase energy production up to four[2] and up to five[24] times that produced by machines without mechanical motion rectifier (MMR). In addition, it has been found that the MMR can reduce the shock conveyed to the vehicle and improve vehicle comfort while going over the speed bump[2].

In our study, we introduce a new setup of the rack-pinion mechanism with MMR. We have used two light racks that drive one pinion in turn so that the pinion receive clockwise torque during the upward and downward motion of the rack.

2. DESIGNING THE MACHINE

In this project, we have used a rack and pinion (freewheel), gears and pulley belt that transform the potential energy of vehicles to rotational motion of a generator that then generate electricity. We have designed a rack by clamping a bicycle chain in a u-shaped iron sheet as shown in figure 1 (b).



(a) **(b)**

Figure 1. (a) The rack system and flexible speed bump made of plates joined using hinges (b) Chain clamped inside a U-shaped strong iron sheet to make a rack

(a)

(b)

Figure 2. Figures showing the machine designed in this study.

The rack has two sides, the right and the left rack. This design of the rack results to a very light rack hence a small force will be required to lift it during the upstroke. This minimise energy loss in the rack system. We have fixed two rack-position control wheels that ensure the rack is at the right position while moving. These wheels move on two 9 cm rails that determinetheir location at any point of the rack motion. Wehave four deviation plates (two right- and two left-deviation plates) with one end fixed and the other joined to a spring. These plates move the rack sideways when it reaches the top and bottom positions to ensure that the two racks drive the pinion in turns.

We have combined a pinion, gears, flywheel and a pulley belt as shown in fig6. The driving/effort pulley is mounted on flywheel shaft while the load pulley on the DC generator shaft. A bicycle freewheel acts as the pinion. All gear-shafts have been fixed with bearings to reduce friction in the system.

3. HOW IT WORKS

3.1. RACK SYSTEM

When a vehicle runs over the rack head the rack moves downwards. After the vehicle tyre has moved past the speed breaker (the bump), the rack is pulled up by the return springs. While the rack is in motion, it provides torque to the pinion/freewheel making it to rotate in a clockwise direction. In our discussion, we have divided this motion into two: the down stroke and the upstroke.

3.2. DOWN STROKE

In this stroke, the rack moves downwards. The right arm of the rack (right rack)produces a clockwise torque on the pinion that makes it to rotate in a clockwise direction.During this motion, the two rack-position control wheels roll on the left side of the rails. This controls the position of the rack such that the teeth of the right rack do not leave or slip over the cogs of the pinion/freewheel. On reaching the lowest point, the rack is pushed to the right by the right-deviation plates. The left arm of the rack (left rack) now touches the pinion and the system is ready for the upstroke. During the down stroke motion, the return springs are stretched to gain enough potential energy that is used to push the rack upwards during the upstroke.

3.3. UP STROKE

The upstroke is facilitated by the compression of the return springs. As the springs compress, they push the rack head upwards back to their original position. During this upward motion, the left rack produces a clockwise torque on the pinion hence it continues rotating in the clockwise direction. The two rack-position control wheels move to the opposite side (right side) of the rails i.e. rolls on the right side of the rails.This ensures the left-rack teeth and the pinion cogs are held in position; they do not leave or slip over each other. On reaching the highest point, the rack is pushed to the left by the left deviation plates. The right rack now touches the pinion and the system is ready for the down stroke. This process will repeat itself whenever a vehicle runs over the speed bump.

3.4. RETURN SPRINGS

Six identical springs each of spring constant $K = 580.63\ N/m$ push the rack back to the top after a downward push. These springs are arranged as shown in figure3.

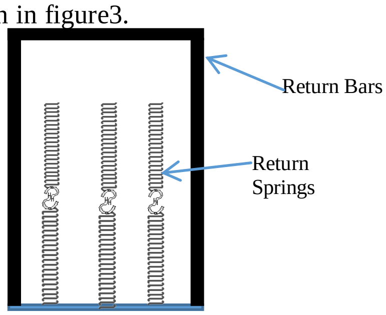


Figure 3.Arrangement of return springs and return-bars.

This combination gave us a spring constant of 870.968 N/m ascalculated below:

$$K_R = \frac{3}{2}K \qquad (1)$$

$$= 870.968 N/m$$

Where, K_R is the spring constant of the return spring system.During the down stroke motion, the spring's extension goes up to about 10 cm. Therefore, by making the calculations below, we can estimate the maximum force that they produce as they compress to their original length.

Using Hooke's law, we find that, the force F_R produced by the return spring system at an extension e_R is given by,

$$F_R = K_R e_R \qquad (2)$$

$F_R = 870.968\ e_R$ (**Error! Bookmark not defined.**)

Theforce that the return spring system exerts on the return bar reduces with a decrease in their extension according to equation (2) or (3).

Some of the force produced by the return spring is usedto push the deviation plates. This give the deviation plates a potential energy that is then used to push the rack sideways.Another fraction of this force is used to overcome the weight of the rack. However, our rack has been designed in such a way that it is as light as possible. Therefore, the force required to lift it will be very small. Therefore, there is minimal energy wastage in the rack system. This ensures efficiency of the machine.

3.5. DEVIATION PLATES

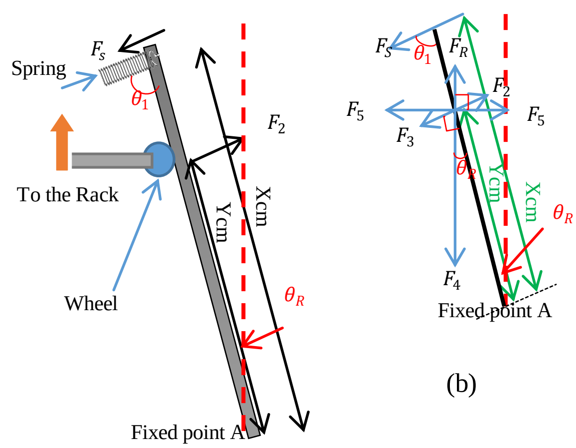
The deviation plates assist in pushing the rack sideways by utilizing the elastic potential energy of small springs of spring constant, K_1,of about $821.43 N/m$. These plates are levers with one end fixed and the other end attached to a spring.Their length X is about 12cm. These plates are inclined at an angle θ_R to the vertical such that, while the rack is moving to the bottom or top positions, it pushes the plates making the springs attached to their ends to stretch. This tension of the springs then pushes the deviation plates that then push the rack to the left (left deviation plates) or to the right (right deviation plates). Because of this force, just after the rack-position control wheels move past the rail, the rack is forced to move to the left or right.

We found that, when the rack is at the top most or at the bottom most points, the springs on the deviation plates stretch by about 1.6cm. On compressing, using Hooke's law, each spring produces a force of 13.143 N on the deviation plate. In general, the force, F_s produced on the deviation plates by the spring of spring constant K_1 and extension e_1 is

$$F_s = K_1 e_1 \qquad (3)$$

The component of this force that is perpendicular to the deviation plate is,

$$F_1 = K_1 e_1 sin\theta_1 \qquad (4)$$



(a)

(b)

Figure 4. (a) The left deviation plates when rack is moving upwards during the up stroke (b) A sketch showing the force components that act on the deviation plate.

To get the force, F_3 exerted on the rack by the deviation plate we use the principle of moments. Taking moments about the fixed point A, at equilibrium,

$$Clockwise\ moment\ =\ Anticlockwise\ moment$$

$$F_3 \times Y = F_S sin\theta_1 \times x$$

$$F_3 = \frac{X K_1 e_1 sin\,\theta_1}{Y} \qquad (5)$$

The component of F_R that push the deviation plate (acting perpendicular to the deviation plate) is given by,

$$F_2 = F_R sin\theta_R$$

$$F_2 = K_R e_R sin\theta_R \qquad (6)$$

The horizontal force component F_5, due to F_1, that then push the rack sideways is given by,

$$F_5 = F_3 cos\theta_R$$

Using equation (6), we get,

$$F_5 = \frac{X K_1 e_1 sin\,\theta_1 cos\,\theta_R}{Y} \qquad (7)$$

It is obvious that there will be some resistance to the force F_R because of the deviation plate. The force component acting against F_R is given by,

$$F_4 = \frac{X K_1 e_1 sin\,\theta_1 sin\,\theta_R}{Y} \qquad (8)$$

Since θ_R is very small and $Y > {}^1/_2 X$, F_4 is very small compared to F_R (ie. $F_4 \ll F_R$). Therefore, most of the force F_R is used to drive the generator. This is important as it ensures a minimal energy is wasted in the rack system.

It is expected that, at equilibrium F_3 will be equal to F_2 but this situation does not occur in this machine. The force F_2 is always greater than F_3 (i.e. $F_3 \ll F_2$).this enables the rack to move to the top and bottom points unstopped. The choice of springs on this study was dictated mainly by availability and therefore more studies may be needed to establish the most suitable combination of springs.

3.6. THE GROOVE

The groove is fixed to the return bars. Its purpose is to disconnect the rack from the return bar. This makes it easy for the deviation plates to push the rack sideways. Since the return bars do not move sideways, if the two were fixed together the rack would not be able to move sideways.

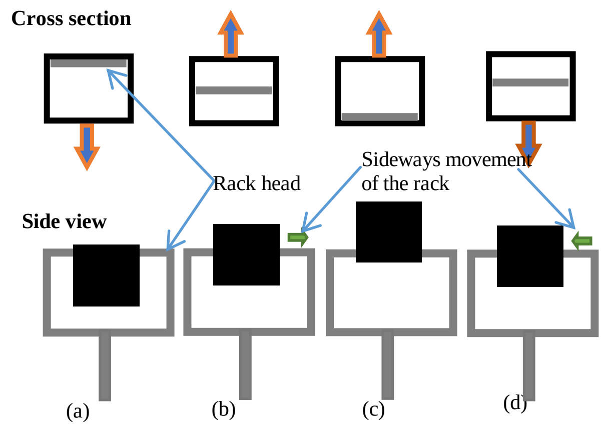


Figure 5. a cross-section and side view showing the position of the rack head in the groove when (a) rack is moving downward (b) rack changing direction at the lowest point (c) rack moving upward (d) rack changing direction at the uppermost point

During the down stroke, the rack-head touches the upper part of the groove as seen in fig5(a). At the bottom when the return bar changes direction, the rack-head changes position to touch the lower part of the groove (Fig5(b) and (c)). During this change, the rack-head and the groove go through a time of freeing i.e. a period when the two are not touching each other (Fig5 (b)). This disconnects the rack from the return bar enabling the right deviation plates to push the rack to the right. The rack-head touches the lower part of the groove when the rack is moving upwards. At the top most point, when the return bar is pushed downwards, the rack-head will change position from the lower side of the groove to the upper side. During this period, the rack-head and groove go through a period of freeing again (Fig5. (d)), this makes it easy for the left deviation plates to push the rack to the left.

3.7. THE RAILS

The rails are 9cm long metal plates fixed on the rack system. They are well designed and fixed such that they make the racks and the pinion to firmly, cling together. This is done by accurately calculating the distance the rack needs to move sideways. This dictates the radius of the rack-position control wheels. The wheel roll on the rails compelling the rack to move in a straight vertical line and in a predetermined horizontal position preventing the teeth of the rack and that of the pinion from leaving each other or slipping over each other when the machine is being used.

3.8. THE GEAR SYSTEM

The pinion/freewheel is driven by the rack in the clockwise direction. This motion is increased using gears and a pulley belt system. The velocity ratio of this combination is 0.0198. This means if the pinion makes one turn, the generator make about 50.5 turns.

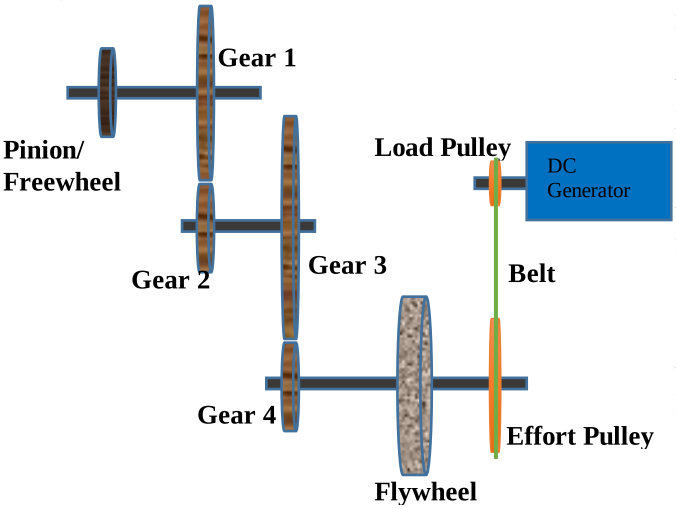


Figure 6. The gear system showing the arrangement of the pinion/freewheel, gears, flywheel, pulley belt, and the DC generator

The calculations are as shown below.We know that the velocity ratio of a gear systemis given by,

$$V.R = \frac{\text{no.of teeth of the driven}}{\text{no.of teeth of the driver}} \quad (9)$$

For gear 1 and 2

$$V.R_{1,2} = \frac{12}{34} = 0.3529$$

For gear 3 and 4,

$$V.R_{3,4} = \frac{25}{73} = 0.3425$$

The velocity ratio of the pulley belt

$$V.R_p = \frac{\text{radius of the driven pulley}}{\text{radius of the driving pulley}} \quad (10)$$

$$V.R_p = \frac{1.0\text{cm}}{6.1\text{cm}} = 0.1639$$

Therefore, the velocity ratio of the whole system is given by,

$$V.R = V.R_{1,2} \times V.R_{3,4} \times V.R_p \quad (11)$$

$$V.R = 0.3529 \times 0.3424 \times 0.1639$$

$$V.R = 0.0198$$

However,the velocity ratio of the whole system is:

$$V.R = \frac{\text{no. of revolutions made by the pinion}}{\text{no. of revolutions made by the small pulley}} \quad (12)$$

So we can calculate the number of revolutions made by the generator/the load/driven pulley,

$$0.0198 = \frac{1\text{ rev}}{z}$$

$$z = 50.5\text{ revolutions}$$

From the calculations, we find that, if the pinion makes one revolution, the generator make about 50.5 revolutions.

In a full stroke (down and upstroke), the rack moves through a vertical distance of 20 cm. This makes the pinion to make1.5 revolutions; in that case, the generator makes about 75.75 revolutions. Since the gear system continues rotating for sometimes after the rack has stopped, the generator will make even more revolutions in one full stroke. The DC Generator converts this rotational motioninto electricity.

In this project, we have used a bicycle's freewheel as the pinion. This freewheel plays two roles: as a normal pinion and freewheel. As freewheel or overrunning clutch it disengages the gear system from the rack when the rack stops moving. This enables the gears to continue rotating for some time after the rack has stopped. This time depends on the size of mass that is placed on the rack head (or the velocity of the rack that is produced by the moving object) as seen in this study.

The flywheel is used to increase the machines momentum. This ensures that the gears continue rotating for some time after the rack has stopped moving. Our flywheel has a mass of 6.7kg.

4. THE SPEED BUMP

The speed bump is designed such that it can move about 10 cm downwards. A Flexible speed bump is designed using strong plates joined by hinges or rubber (seefig 1). The plates run over rollers to reduce friction with the road surface.Other researchers have described the flip plate mechanism [29] of designing the speed bump.

5. DATA ANALYSIS

We carried out experiments to determine the suitability of our machine. We have used a DC motor as the generator. We connected a bulb, voltmeter and an ammeter as shown in the following circuit.

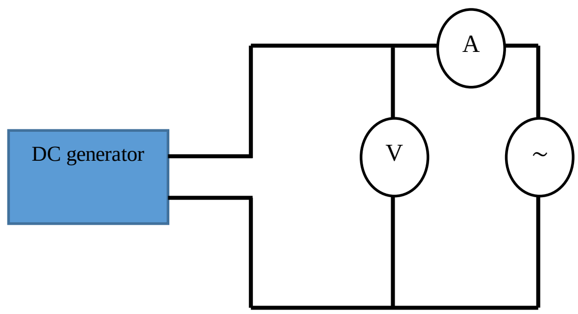


Figure 7: A diagram showing the circuit used in this study.

We took blocks of masses 26kg, 30kg, 31kg, 33kg, 37kg, and 40kg. Then we placed each at a time on the rack-head and measured the time for the down stroke, time for upstroke, the time of rotation after the rack has stopped, the current, and voltage produced. For comparison purposes, this has been done while the machine is utilizing only the down-stroke to rotate the pinion, and when it is utilizing both strokes.

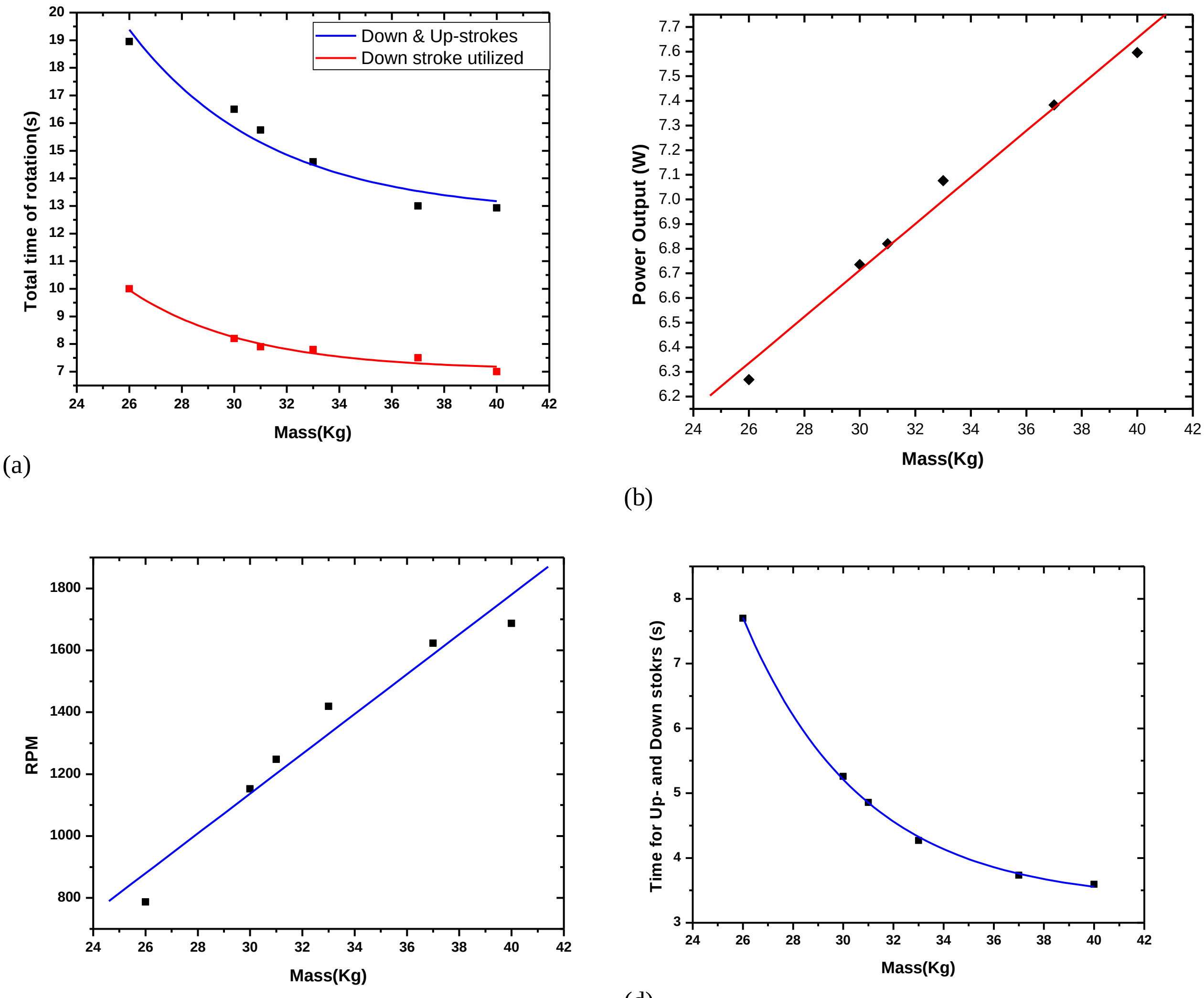


Figure 8.(a) Graph of Total time of rotation against mass; the red curve shows the variation when only the down stroke is utilized, while blue curve shows the variation when both the down and up strokes are utilized to rotate the pinion, (b) graph of power output against mass, (c) graph of RPM against mass, (d) graph of time taken by the rack to make one full stroke against mass.

A graph of total time of rotation against mass is an exponential curve as shown in fig 8(a). From the graph, we see that the total time of rotation decrease with increase in mass that is placed on the rack. This is because for a larger mass, the rack travels faster and takes shorter time to go through to the bottom and up to the original top position. However, we found that, the curve when the two strokesare utilized is higher than that obtained when the system is utilizing the down stroke only. This shows that a rack that utilizes both down and up strokes to rotate a pinion increase the rotation time of the generator significantly. The time of rotation of the generator increased by about 89.2% of the time of rotation when the machine utilized the downward motion only.This means that the generator will produce current for quite a longer time compared to a system that utilizes the down stroke only. This ensures a larger electrical energy is produced.

A graph of electrical power against mass is a straight-line graph with a positive gradient. This shows that the higher the mass placed on the rack head, the higher the power produced. Increasing this mass increased the velocity of the rack during the down stroke. This causes the pinion to rotate faster leading to higher RPM as shown in the graph of RPM against mass. This leads to higher power output. This relationship between RPM and mass can be used to design a more suitable generator for this machine.In case of AC generator, one may have to use a current frequency changer or converter [30]to maintain a good frequency of the current produced.

Our machine producedelectrical power output that range from 6.268W to 7.596W when masses of 26Kg to 40Kg were placed on the rack head.From the graph of power output against mass,we extracted the relationship of the two variables as,

$$Power\ output = 3.88441 + 0.09428m \quad (13)$$

Where m is the mass, in kilograms, placed on the rack head.We predicted that if a car of mass 1 tonne run over the rack head, a Power output of 98.16Wwill be produced, however this depend on the capacity of the generator used.

A graph of time (Down stroke time plus Up-stroke time) against mass is a curve with negative gradient. This shows that the larger the mass the shorter the time taken for the rack to move to the lowest point and back to the top.More studies need to be done to establish the most appropriate time. This time should be suchthat after the front tyres of a car pass the speed bump, the rack will move up to the top before the back tyres steps on it. This shall ensure that the potential energy of the vehicle is utilized well.

The efficiency of the machine has been estimated using the formula

$$Efficiency = \frac{Power\ \ output}{Power\ \ input} \times 100$$

(14)

Where, $Power\ Output = Current \times Voltage$

$$P = IV \quad (15)$$

And, $Power\ Input = Weight\ on\ the\ Rackhead, mg \times Distance\ Travelled\ by\ Rack, d$

$$P = 0.1mg$$

(16)

Since $d = 0.1m$

We have achieved an efficiency of about 21.7%. However, this can be improved by replacing the generator with a higher capacity one. This will increase the power output hence the efficiency.

6. CONCLUSSION

In this project, we have discussed a new rack-pinion mechanism with MMR. It has been shown that this kind of rack system increase the rotation time of a generator 89.2% compared to devices without MMR. We have achieved a power output ranging from 6.268W to 7.596W when masses from 26Kg to 40Kg were placed on the speed bump. The power output can be increased by arranging several machines in series [15] and/or by using a generator with higher capacity. The efficiency of the machine was found to be about 21.7%. The power generated by this machine can then be stored in batteries for use. This makes it convenient since power can be supplied even if there are no vehicles passing over the speed bump.

7. ACKNOWLEDGMENT

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8. FUNDING

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