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Speed Breaker Energy Harvester Using Roller Mechanism

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Abstract: ***Increasing and renewing energy resources are needs of the times. Many effortsare spent to generate power from the speed breakers and many mechanisms are implemented for this goal. In this paper, these mechanisms will be reviewed and how the power is generated from each mechanism. In addition,this paper will provide and discuss an experiment of generating the power from a roller mechanism after brief description of the overall system implementation, connections and description.Results presented in this paper reveal that the implemented prototype roller mechanism has been able to produce up to 830 watts of peak power, which is sufficient for lighting signs, traffic signals and monitoring roads, especially when compared with the other mechanisms reviewed in this paper.***

Keywords: Speed breaker, Energy harvester, Roller, Traffic, Cat Eyes

1. Introduction & General Review

Energy is the main source that drives everything in the globe. Human being's energy demand is continuously increasing, although the resources are limited and cannot be replenished in short periods. Therefore, scientists are trying to utilize renewable energy resources. Governments are putting efforts to make the public aware of saving power and engineers are doing their best to modify the electromechanical systems' efficiency. One of the most creative ideas is to inverse the problem of crowding in the over-populated cities into a power source. The idea is to make use of the thousands of kilometer long roads, that are occupied by thousands of moving vehicles to harvest energy [1],[2].

The use of the speed bump was reported to be in 1906 in the town of Chatham, New Jersey, United States, as a raised crosswalk 5 inches above the road [3]. The "Holly hump" in 1953 [4] has been designed by Arthur Holly Compton, who won the Nobel Laureate in physics. He made the forerunning design of the present-day speed bump profile, which was gentler, elongated, and ramped in the nature. The "Holly hump" became a common practice across the world and it has been effectively reducing the vehicles' speed in the areas, where human traffic interaction is high. The idea of converting the kinetic energy to an electrical energy when the vehicle passes over the speed bump implemented initially in South Africa. This electrical energy can be used to light up small villages during the electrical shortage [5].Since that time, the use of SpeedBumps Energy Harvester (SBEH) has started.

Many efforts [6], [7] have been made to generate power from vehicles passing over speed breakers. This quick review will present how energy can be generated by using common road speed breakers. Figure 1 shows the general block diagram of different mechanisms used to harvest energy from speed bumps. Studying the electrical power generated from SBEHs is reducing the load demand on conventional power plants [8]. Consequently, studying the electrical power generation of SBEH will consider road traffic to be a new green energy source.

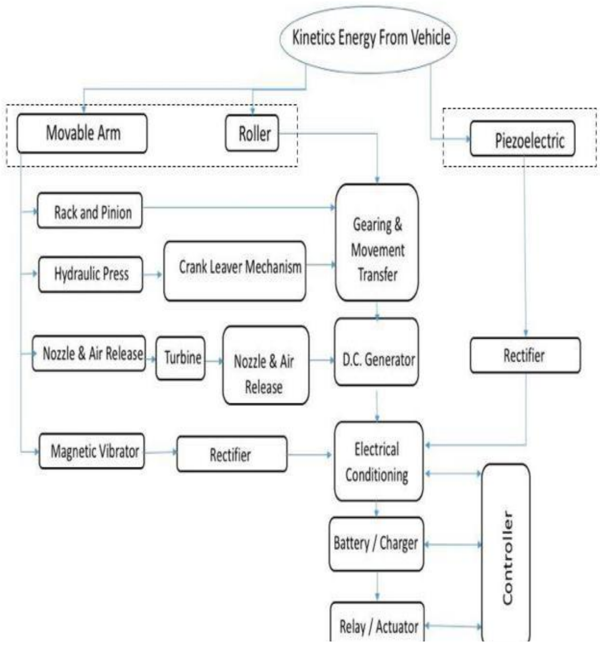


Figure 1: Generalized Block Diagram for SBEH

Speed Bumps Energy Harvester (SBEH) are classified into two major parts. The first part is when SBEH is moving,such as the roller mechanism or in the mechanisms of rack and pinion, hydraulic press, compressed air or magnetic vibrator mechanism. The second part is when SBEH is not moving such as in the piezoelectric mechanism. The following part of this paper will highlight samples of energy generated from those mechanisms depictedin Figure 1.

a) Piezoelectric SBEH Mechanism

Piezoelectric materials have the ability to produce electrical energy from mechanical energy. The vibrations produced from the contact between cat eyes or speed bumps are converted into electricity [9]. Whenever a vehicle passes over a speed breaker, the speed breaker deflects the piezoelectric material vertically. Using a synthetic speed breaker with embedded piezoelectric generators, part of the energy due to deformation is transformed into an electric energy through direct piezoelectric effect. The piezoelectric material is bounded between the upper A and the lower B components of the synthetic speed breakers demonstrated in Figure 2. The upper part can be detached from the lower part, and the lower part is fixed to the road [10], [11].

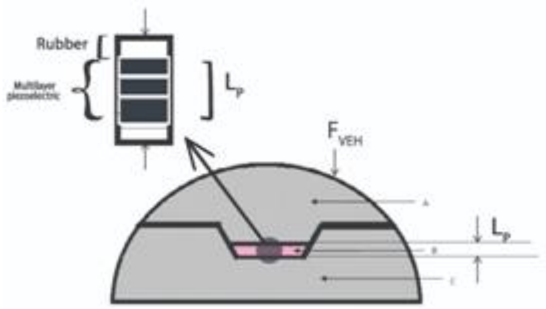


Figure 2: Piezoelectric parameters [11], [14]

A piezoelectric transducer is used as an input to the converter,then converting the AC to the DC supply. The converter output is connected to the 12V battery, and its output is passed to the inverter thento the relay driver circuit, which is controlled bya controller [12],[13].The vertical deflection of the speed breaker is proportional to the vehicle weight. With the same principle of work an intelligent design, model and analysiswas represented in [14]. This mechanismincreases the pressure on the multilayer piezo electric and harvesting energy from vehicle suspension.

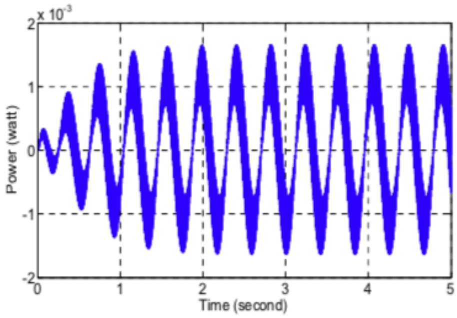


Figure 3: Generated power from multilayers of piezoelectric mechanism [14]

Another model uses a piezoelectric material, connecting wires, led, capacitors and a pushback mechanism [15]. The piezoelectric buzzers will also be connected to the transistors in order to store the voltage produced by the piezoelectric material, when applying pressure on them [15]. The range of power generated from the piezoelectric mechanism is demonstrated in figure 3. Selection of piezo electric for SBEH can be found in [16] it was concluded that the energy increases with the decrease of piezo electric area. The range is in milli-watts and needs a lot of work in signal conditioning level to isolate and generate energy from SBEH.

b) Rack and Pinion SBEH Mechanism.

Rack and pinion mechanism is used to convert rotary to linear motion. Flat toothed part is the rack, while gear is the pinion. Whenever a car is crossed the speed breaker, the dome is pressed downwards [17]. The rack attached to the bottom of the dome moves downward and consequently the pinion rotates. Through multiple series of gear drives, the speed of the gear rotation is multiplied to higher speed that is enough to power the generator. Figure 4 is a sample of the power generated from rack and pinion mechanism. It shows the results from the experiment in [18] for a car passing over the rack and pinon SBEH mechanism.

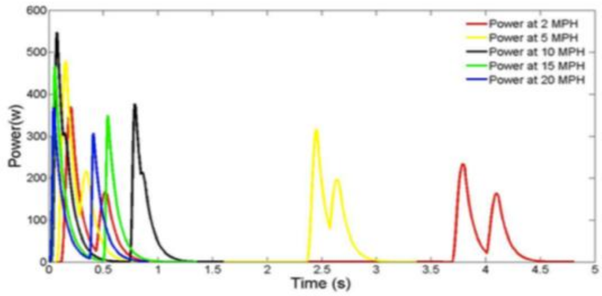


Figure 4: Power generated from the rack and pinion mechanism experimented with different speed [18]

Experimentally prototype used in [19],[20] of a ramp used to reduce the velocity of the vehicles. Applied different masses as an input, measuring voltage and currentproduced and found that the voltage and current have a liner relation with the mass that makes the power generated.

Figure 5 demonstrates the schematic, prototype and the principle of work for SBEH of rack and pinion mechanism.

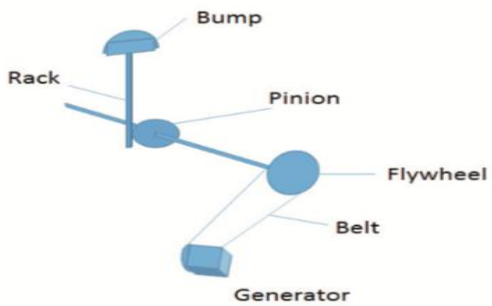


Figure 5: Schematic, principle of work for SBEH of rack and pinion mechanism [10]

A case study of using the mechanism of rack and pinion is used to generate power. 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 twenty-four hours. This power is sufficient for lighting a street [21],[22]. The output power generated from rack and pinion mechanism is the nearest value of power generated from the roller mechanism experimentally. The roller can generate more power with the same vehicle weight. Rack and pinion mechanism loses power in gearing and mechanical movement transfer verses the roller mechanism.

c) Hydraulic Press &Compressed Air SBEH Mechanism

This mechanism uses the weight of the vehicles to push a cylinder actuator that has fluid (oil) with non-return valve that pushes the other accumulator connected with a flywheel to hydraulic generator [23]. Additionally, there is another way using compression of air through a non-return valve when the vehicle passes over the SBEH. After that, air will be released to an air turbine for electricity generation [24]. Combination of hydraulic press and crank lever mechanism is used in [25] to generate electricity with a more efficient method. The used principle is Pascal's Law. The constant pressure, which is coming from the applied force on the plunger area, is transferred to the ram. The difference in area for the ram on which that makes the difference in force [26]. This makes a small force applied on the plunger, is able to lift heavy loads placed on the ram. An intelligent design is presented and modelled for harvesting energy from hydraulic press in figure 7. The power generated from this mechanism is more sufficient, when compared with the previous mechanisms, this will be shown in figure 6, the output power at the peak point is between 7kW to 8kW [27].

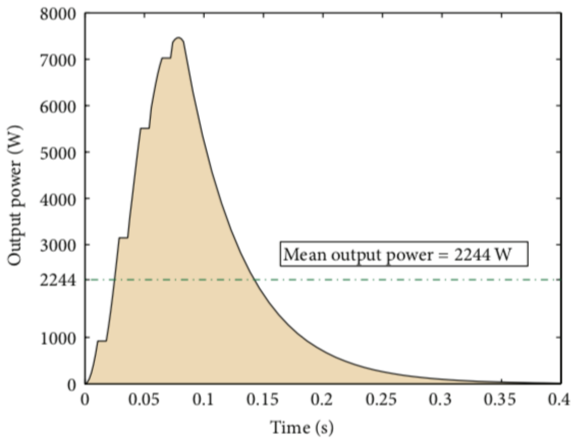


Figure 6: Overall output power, which is harvested from one-wheel strike at vehicle speed (40 km/hr) [27]

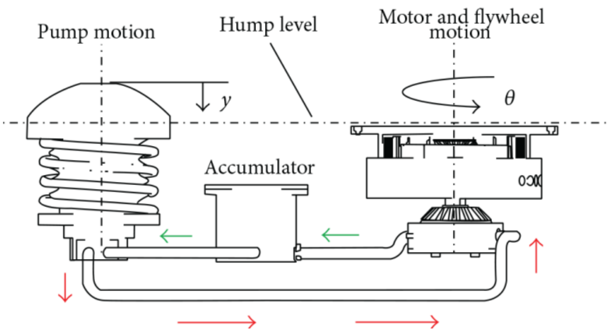


Figure 7: Intelligent design modelled for harvesting energy from hydraulic press [27]

In air compression method, the vehicle passes over the speed breaker, and then the piston of the pump goes down with air compressed through the non-return valve. The principle with details is presented in [28], [29]. Figure 8 demonstrates the air compression mechanism diagram.

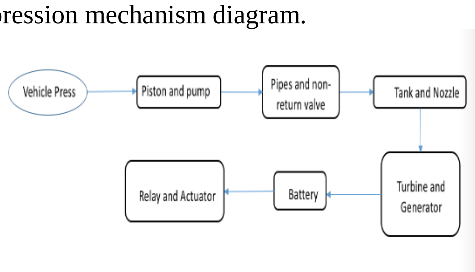


Figure 8: Compressor methods diagram.

In a different way, a project has been represent non-conventional way to compress air in cylinder and store this energy to a tank by the kinetic energy from the vehicle. Producing compressed air using vehicle suspension consider a green method taking advantages from driving vehicle suspensor [30]. Harvest energy from the car itself, it will be costly to fix a device for each car. Therefore, harvesting the energy by implementing only one device in the infrastructure of the road will be taking advantages of the kinetic energy from each single vehicle passing over this device.

d) Magnetic Vibrator Mechanism for SBEH

One of the inventive ideas for harvesting energy is vibration. It is called a spring coil mechanism, which is a movable arm connected directly to the speed bump [31]. Figure 9 demonstrates the principle of the magnetic vibrator harvesting energy system. The spring mass elements moves when the vehicle moves. The generated magnetic field is surrounded by the stator (stationary casing) with wound copper coils. Once the motion on the SBEH happens, the magnetic field is generated through these copper coils, and consequently the electricity will be generated [32].

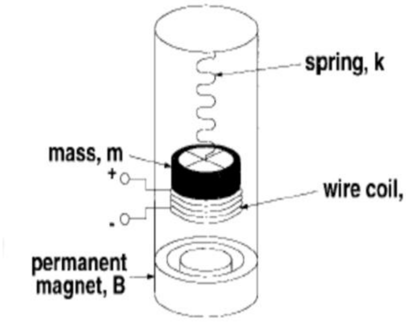


Figure 9: Magnetic vibrator - spring mass harvesting energy system

Most of researches obtain 10 µW to 100 mW power from spring coil mechanism. In [14] a magnetic mechanism built from translators and stators. When the vehicle passes over the bump, the translators move downward and generate power in the stators. This power is suitable for limited application such as the low-power electronics or self-powered wireless sensors [33], [34]. A comprehensive review has been provided in [36] for large-scale power harvested from vibration energy ranging from 1 W to 100 kW. Due to this, low scale power and limited application specially the SBEH that is moving in low frequency for the stator and rotor to generate power [35]. Table 1 shows as per Texas Instruments Energy harvesting in [33], the harvested power against the vibration source.

Table 1: Harvested power against the vibration source [33]

Energy from vibration motion	*Harvested Power*
Human	4 µW/cm2
Industry	100 µW/cm2

Vibrator mechanism is one of most promising technologies for generating energy for applications such as supply wireless sensor or micro-robot application. However, in large scale of applications such as SBEH for lighting roads, micro power scale is not sufficient, especially when compared with roller mechanism.

e) Roller Mechanism for SBEH

In the roller mechanism, the vehicle passes over the speed breaker leading to a friction force between vehicle wheels and the roller generating rotational motion. This rotational motion is used to generate energy directly. The most important parameter of the roller mechanism is the friction force between wheels of vehicles and the roller. Rubber does not have a single constant coefficient of friction. The coefficient depends on temperature and surrounding environment parameters. The ideal method of determining the coefficient of friction is by trials and it is depending on the materials [43].In [37]a project with block diagram is represented for roller to produce electrical power using bike (two wheels vehicle). In addition, samples of previous work present for roller mechanism in [38], and [39].Most of the experimental studies on the roller mechanism was examined using two wheels vehicles only.

2. Roller Mechanism and Experimental Work

One of the main advantages of the roller mechanism is the direct movement transfer (rotational motion) from the wheels vehicle to the generator. This direct rotational motion transfer does not exist in the hydraulic or rack-pinion mechanism. Depending on the gear ratio between the pulley on the roller and the pulley on the generator, the power will be calculated. In addition, the disadvantages of piezoelectric and magnetic vibrator mechanisms such as the effectiveness of noise and low power generation are null in the roller mechanism. The expenses of implementation and maintenance for roller mechanism is too low if compared with the hydraulic or air compression mechanisms. Finally, no extensive experimental studies has been done on roller mechanism.

a) Roller Mechanism Implementation

A few efforts spent on the roller mechanism experimentally. The effect of vehicles passing over rollers with different speeds will be highlighted. Also, will represent a roller mechanism implementation with brief description and discuss the results.

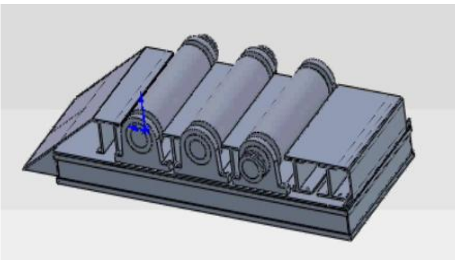


Figure 10: Roller mechanism design

b) Roller

Rollers have been made up from cast iron material. The physical properties of the gray cast iron material make our bar strong enough to bear the weight at our experiments [40]. Figure 10 shows the roller mechanism design, whichis implemented and showed in figure 11 and figure 12. Roller has been covered by 3mm thickness rubber, to increase the coefficient of friction descried in equation (1).

c) Bearing selection

According to SKFbearing selection procedures, the required performance of the selected bearing is to withstand with a massive impact force of the vehicle with the shaft mounted on the bearing, to have a suitable life time to reduce maintenances cost (in this case maintenance means that the road will be closed). Bearing should be capable of receiving combined forces including radial and axial forces. It should also have a high stuffiness [SKF], [41]. The type of bearing used here is rolling element type.

d) Pulley

The larger pulley in our system transfers the motion from the roller known as driver pulley and the smaller pulley attached to the generator and connected together through a belt. The ratio between them is approximately 6.67.

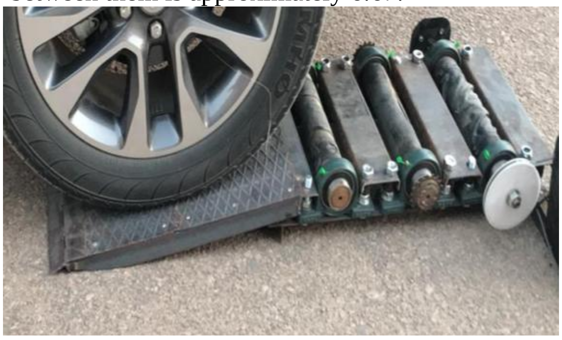


Figure 11: Roller system implemented and prepared for Car experiments

Figure 12: Roller system implemented and prepared for Motorcycle experiments

e) Electrical/Electronic connections integrated with Software

Figure 11 summarizes the electrical connections between the experiment elements to get the output on the LABVIEW software.

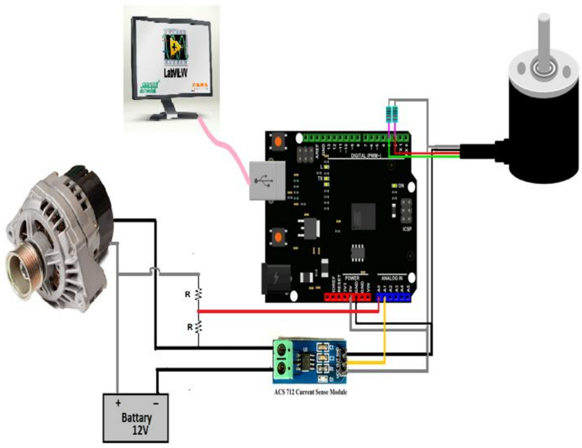


Figure 13: Electrical diagram for the component used

In figure 13, the Arduino Uno is used as a controller to read the output from the sensors, battery and DC generator, then LABVIEW software is used. Sampling current sensor module is connected to analog input A1 pin at Arduino to measure the output current from the generator. Incremental encoder is used to measure the roller speed then generate a number of pulse to the digital input pin 2. After Arduino takes these measurements, it sends it to PC by serial communication, then LABVIEW software monitor and analysis these signals. Moreover, using empirical method to drive roller equation and coefficient of friction then modeling with LABVIEW in Figure 14. The three main equations can describe the roller mechanism and the force as below. First the reaction force in equation (1) is the multiply of the driving force and the coefficient of friction. Secondly the driving force effecting the roller is in equation (2) with taking the gearbox ratio (η_g) and final drive ratio (η_o) in consideration. Finally, the equation of motion in case torsional will not affect the roller, can be descripted in equation (3) as below.

$$F_{fr} = F_d * \mu \qquad (1)$$

$$F_d = \left[\frac{\tau_e}{r_r} * \eta_g * \eta_o\right]$$

$$F_{fr} = \left[\frac{\tau_e}{r_r} * \eta_g * \eta_o\right] * \mu \qquad (2)$$

$$F_{fr} * r_r = J_r\theta''_r + C_r\theta'_r$$

$$\left[\tau_e * \eta_g * \eta_o * \mu\right] = J_r\theta''_r + C_r\theta'_r \qquad (3)$$

Where the F_{fr} is the friction force, F_d is the driving force from vehicle wheels, τ_e is the engine torque, r_r is roller radius, and μ is coefficient of friction. Theta is function in time, which will be integrated according to the contact roller arc length.

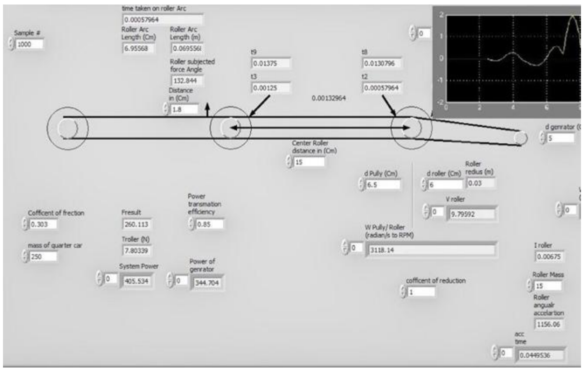


Figure 14: Sample of modeled roller output, while rare driver wheel vehicle passing

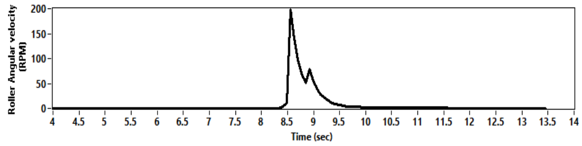
When the moving vehicle passes over the roller, the friction force between vehicle's wheels and the roller rotates the roller. A pulley connected to the roller will transfer the rotational motion to the generator pulley through belt. The sensors used to measure the volt, current and roller revolutions then the output is used to calculate the power. Figure 11 and 12 demonstrates the implementation of the roller mechanism which is prepared for the experiment.

f) Result from Car-Roller Experiment

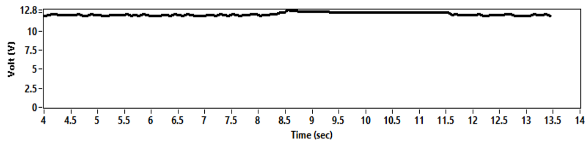
This experiment performed with a car "Mitsubishi lancer model of 2014". The curves below are based on the parameters of car weight, car velocity that is 10 Km/hr., roller inertia and parameters in Table 2.Diameter Ratio between roller pulley and generator pulley is 6.67. In addition, generator angular speed can be calculated by multiplying the diameter ratio with roller Pulley angular speed.

Table 2: Specification and parameter used for car experiment

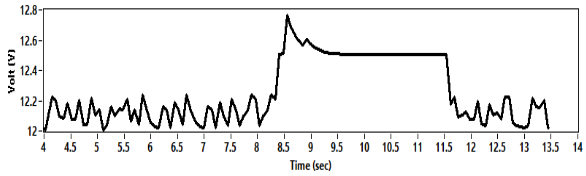
Specification	Value
Wheels diameter	38.1 cm
Roller diameter	5 cm
Roller arc contact length	6.0126 cm
Distance between wheels center	270 cm
Roller pulley diameter	20 cm
Car velocity	10 km/hr.
Generator pulley diameter	3 cm
Battery	12-volte



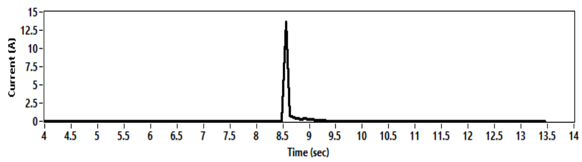
Figures 15: RPM vs Time.



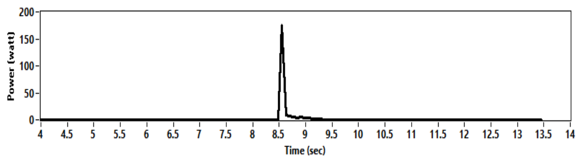
Figures 16: Voltage vs Time.



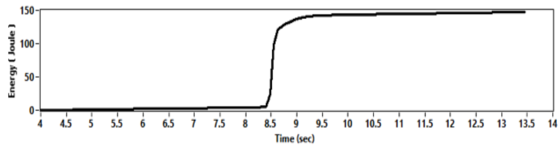
Figures 17: Voltage vs Time.



Figures 18: Current vs Time.



Figures 19: Power (Watt) vs Time.



Figures 20: Energy (Joule) vs Time.

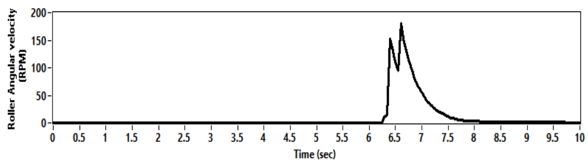
- Car velocity 10 Km/hr
- Roller angular velocity around 198.5 RPM
- Max volt 12.76 v
- Max current 13.74 A
- Max power 175.43-Watt
- Max Energy 147.36 Joule

g) Result from Motor Cycle-Roller Experiment

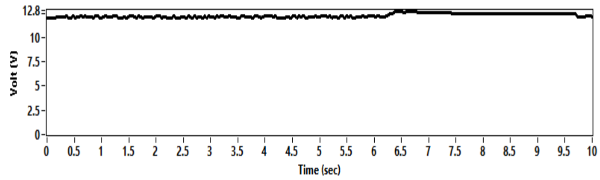
The experiment performed with a motor cycle "SYM jet 14". Experiments done with considered parameter of the mentioned motor cycle weight, motor cycle velocity, roller inertia and parameter in Table 3.Diameter Ratio between roller pulley and generator pulley is 6.67.

Table 3: Specification and parameter used for motor cycle experiment

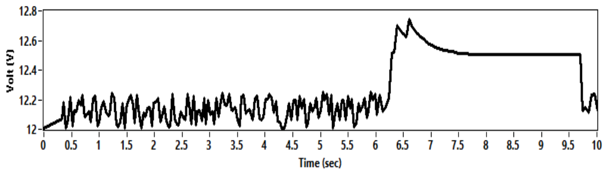
Specification	Value
Wheels diameter	35.56 cm
Roller diameter	5 cm
Roller arc contact length	6.0126 cm
Distance between wheels center	135 cm
Roller pulley diameter	20 cm
Motor cyclevelocity	10 km/hr.
Generator pulley diameter	3 cm
Battery	12-volte



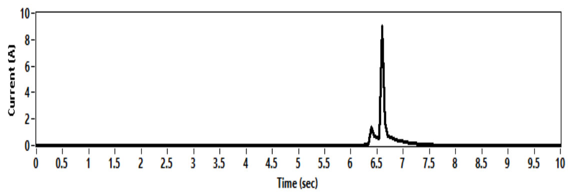
Figures 21: RPM vs Time.



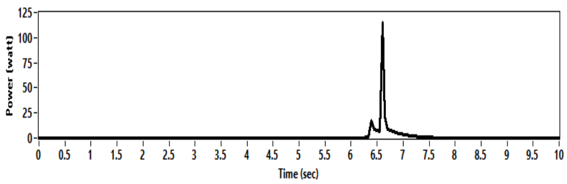
Figures 22: Voltage vs Time.



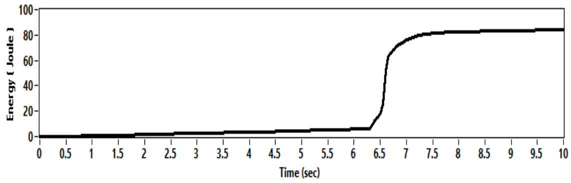
Figures 23: Voltage vs Time.



Figures 24: Current vs Time.



Figures 25: Power (Watt) vs Time.



Figures 26: Energy (Joule) vs. Time

- Motor cycle velocity 10km/hr.
- Roller angular velocity 180.81 RPM
- Max volt 12.74 v
- Max current 9.03 A
- Max power 114.99-Watt
- Max Energy 84.15 Joule

Table 4: Results with different speeds for car

Speed	15 Km/hr.	20 Km/hr.	25 Km/hr.
Max. Power(Watt)	518.35	689.53	830.11
RPM	297.8	397.03	496.29
Max. Current(A)	40.19	52.92	63.07
Max. Voltage(V)	12.9	13.03	13.16
Max. Energy (Joule)	340.82	806.95	1091.48

Table 5: Results with different speeds for a motorcycle

Speed	*15 Km/h*	*20 Km/h*	*25 Km/h*
Max. Power(watt)	425.91	629.53	782.23
RPM	271.21	361.62	452.02
Max. Current (A)	33.11 A	48.49	59.7
Max. Voltage (V)	12.86	12.98	13.1
Max. Energy (Joule)	453.43	908.3	1266.2

3. Discussion

After many experiments with the car and the motorcycle, many parameters need to be taken in consideration. For instance, the car is front-wheel drive and weight of the motor is in the front half of the car so that the peak comes late in RPM curve shown in Figure 14. On the other hands, the motorcycle is rear-wheel drive and the weight of the driver almost at the center so that the peak come late in RPM curve shown in Figure 20. The contact area between the wheels and the roller at the car chassis is nearly triple the motorcycle case.

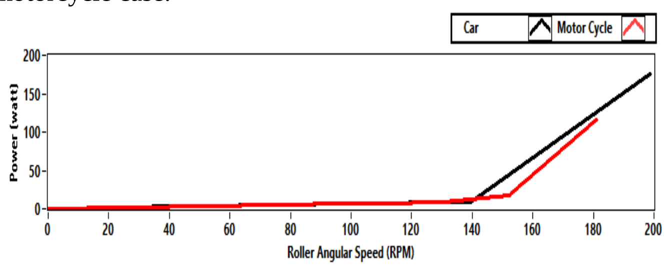


Figure 27: Power vs. vehicle Wheels Angular velocity for speed of 10 Km/hr

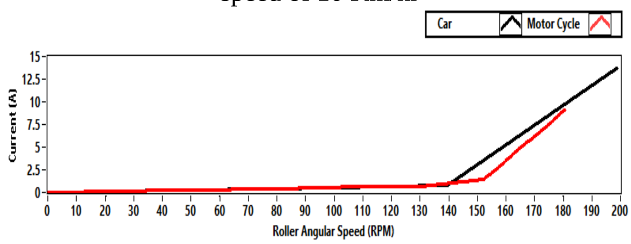


Figure 28: Current vs. Wheels Angular Velocity for speed of 10 Km/hr

Table 6: Sample Result for power generated for car and motor cycle with the same speed

	Car	Motor Cycle
Vehicle Speed	10 km/hr	10 km/hr
Power	175.43 Watt	114.99 Watt

Experiments with different speeds have been collected and represented in table (4)for the car experiments and table (5)for motorcycle experiments for speeds of 15,20 and 25 Km/h. Also, the relation between the generated power, current and the angular velocity of the car wheel is proportional and represented in Figure 26.and Figure 27. when the car or motor cyclepassing over the roller mechanism with speed of 10 Km/hr as a sample in table (6).

4. Future Work

Further Future work on SBEH is needed using different mechanisms. More research effort is needed on Electrical and signal conditioning for piezo-electric and the magnetic vibrator mechanisms. Also, research effort is needed to low Expenses, of maintenance and implementation for hydraulics and compressor air mechanisms to take advantages from high power generated from those mechanisms. Mechanical, soft design and simulation studies need to be spent on rack pinion and roller mechanisms. All this effort to reach the green energy goals of power generation such as sustainability, safe to environment, applicable, and produce more energy for the benefit of more population.

5. Conclusion

The power generated from roller mechanism increases when the angular velocity of the contacted wheels increases. The vehicle angular velocity increases when vehicle speed increases. The maximum power generated from roller mechanism is around 700watt to 830watt per peak. The power generated from the roller mechanism is more than that generated from the piezoelectric mechanism, the magnetic vibrator mechanism as well as the rack and pinion mechanism experimentally. On the other hand, the hydraulic press gives more power, when compared to the roller mechanism.However, maintenance of hydraulic press and implementation from expenses point of view [42] made the roller to be preferred. The advantage of taking the rotational motion in the roller mechanism and avoiding gearing and mechanical movement transfer made the roller on top of SBEH mechanisms. Finally, it is sufficient to chargethe battery, lightning a road, and gathering road information, such as traffic flow and road speed. All these efforts and previous work aretargeting reviewingand experimenting an innovative method for green power generation.

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