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ORIGINAL CONTRIBUTION

Performance of Mechanical Energy Harvesting Unit for Generating Electricity for Portal Gate System

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***Abstract*— The portal gate systems for the parking area need electricity for opening/closing the portal (barrier crossbar) and printing the parking ticket. The Mechanical Energy Harvesting Unit (MEHU) presented in this paper is designed for supplying electrical energy needed by the portal gate system for its operation. The MEHU converted the linear movement of the slider into the rotating movement of the flywheel using rack and pinion. The energy stored in the flywheel is used to turn a small electric generator attached to the energy harvesting unit that provided electricity for the portal gate system. This energy harvesting unit is designed as a breakthrough to produce electrical energy by utilizing the vehicle's weight that enters the parking space. The linear movement of the slider is gained from the weight of the vehicle that passed on the MEHU. This system is appropriate for stand-alone portal gate systems. Three categories of passenger cars (small, medium and large), each with the mass of 1300 kg, 1700 kg, and 2000 kg, respectively, were used in the experiment. The three vehicles used for these experiments were able to produce a maximum rotation of the harvesting unit's electric generator for 2500 rpm, 2890 rpm, and 3140 rpm, respectively. The testing of the harvesting unit's electric generator was done with a continuous rotation. The electrical loads were taken from LED lights with the voltage of 24 Volt, 18 Volt, and 12 Volt produces power of 19 Volt x 3.6 mAmp (4000 rpm), 17 Volt x 4.3 mAmp (3500 rpm), and 12 Volt x 11 mAmp (2400 rpm) respectively. Initial testing of the MEHU shows that this equipment is capable of producing the required electrical energy. The energy stored in the flywheel is used to turn a small electric generator attached to the energy harvesting unit that provided electricity for the portal gate system. This energy harvesting unit is designed as a breakthrough to produce electrical energy by utilizing the vehicle's weight that enters the parking space. .**

***Index Terms*— MEHU, Flywheel, Generator Performance, Electrical Load**

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I. INTRODUCTION

Electricity is one form of energy to support various activities of human life in modern society. The increase of electricity needs occurred in line with the growth of human population in many parts of the earth. If these needs are only supplied from fossil fuel energy sources, then in time there will be an energy crisis because the fossil fuel energy reserves in the earth's crust will be depleting. Energy from the fossil fuels also accounts for a sizeable percentage of air pollution.

Being concerned about how to minimize pollution, a review of some energy harvesting systems that gather energy from sources that are available from industrial or other environments such as mechanical vibrations, temperature gradients, natural or artificial light was proposed [1]. The occurrence of the fossil energy crisis also pushes efforts to obtain a sustainable source of energy for electric power devices or portable systems that generally use small electric power. Furthermore, various studies show that the use of fossil fuels as an energy source also has a negative impact on the environment even in the developing country [2] so that mitigating strategy and long-lasting approach has to be considered to reduce the environmental crisis. The by-products of fuel combustion also caused an environmental crisis that leads to global pediatric health problems. The combustion of coal, oil, gasoline, diesel, and natural gas are caused by air pollution that biologically and psychologically harmful to the developing fetus and young child's health [3].

Considering the increasing electricity demand, it has been developed various designs and researches to obtain alternative energy that meets two criteria namely environmentally friendly and renewable, either from conventional or unconventional energy sources. The conventional energy sources such as hydroelectric power generation that utilizes the height of falling water, thermal power generation that uses geothermal combustion, nuclear power generation that utilizes nuclear fusion, and wind power generation that utilizes wind are usually large scale nature [4]. The large-scale nature means that those power plant systems are centralized power station and to distribute electricity generated to the customers require transmission and distribution cable networks.

At present, various power generation systems from unconventional energy sources are also developed based on the law of conservation of energy. The wasted or unused energy from one system can be changed

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by another system into a useful form of energy. The electrical energy generated is not always on a large-scale, but it can also be only for individual purposes or on a small scale that is sufficient to meet certain electricity needs, such as for the cellular phone battery charging system, or for lighting system in a certain area [5, 6]. The electricity generation system that utilizes the energy of the vehicle's weight even though it is still in the conceptual stage, has been delivered [4], namely by utilizing the rack-pinion pair and gear system. The development of electric energy generation systems from the weight of moving vehicles has also been developed by several researchers [7]. The results of a study [7], stated that kinetic energy released from the four-wheeler when passing the speed bumper can be used to run the air conditioner, charge the battery, street lighting, or for other purposes. A new technique for generating electricity from kinetic energy that is wasted from a running vehicle was discussed by a research paper deal with power generation from the wasted kinetic energy of vehicles. The new technique is to use a roller that rotates when passed by a vehicle. By using the gear and chain system as a power transfer system, the roller rotation is transmitted to rotate the electric generator.

The utilization of wind energy as a source of electrical energy obtained in moving vehicles was conveyed by several researchers [8, 9]. Under ordinary circumstances, when a vehicle is moving there will be a relative (wind) speed between the air and the vehicle. Thus the anemometer and sensor [8] or turbine [9] mounted on a moving vehicle will rotate. Thus the rotation of the anemometer and turbine shaft can be used to rotate the shaft of an electric generator for individual purposes.

By using piezoelectric, an electrical energy can also be generated from mass motion with even small random deviations [10, 11]. The design improvement schemes and techniques for obtaining energy using piezoelectric and electromagnetic has developed, and the results showed that the energy can even be obtained at random movements (arbitrary movement), such as vibrations that occur in the vehicles [10]. Even the electrical energy can also be obtained from static loads, with the mechanism has already granted a patent [12]. The mechanism used a platform to place a load so that the platform can move down vertically to rotate an electric generator.

The use of car or vehicle weights to drive a generator driving mechanism that is capable of producing electrical energy is an alternative way of supplying electrical energy. Utilizing the speed of running vehicles to power an on-road energy harvesting system is successfully implemented [13, 14]. In the midst of the fossil fuel and energy crisis, obtaining a new sustainable source of energy to power portable devices become a new field of research for renewable energy harvesting. The mechanical system as sources of energy can be an interesting alternative to harvest energy [15]. When mechanical energy is available either from vehicles, humans and other vibrating structures, mechanical energy harvesting remains an option that can be considered [16]. Improving the conversion of mechanical energy into electrical energy still becomes an interesting field of research on renewable energy [17] especially for the mechanical energy harvesting unit.

This paper presents the results of the study on a new equipment mechanism and is implemented to obtain electricity more effectively. The new equipment utilizes flywheel, rack, and pinion mechanism to convert linear motion into a rotational one. The use of flywheels as mechanical energy storage is widely used because their ability to store energy can be used for various things [18]. The development and improvement of flywheel design in the automotive field are able to save fuel up to 20% for buses and up to 35% for regular cars [19]. Even for a small scale mechanical harvesting unit, the proper design of the flywheel still have to be considered. To be able to make the most of the energy from the flywheel, the design and selection of the flywheel dimensions must be done carefully to prevent the negative effects of flywheel design inaccuracies. Improper design of the flywheel can harm the mechanism if its angular speed is exceeded [20].

The electricity generated comes from unconventional sources, namely from the potential energy of the weight of the vehicle passing above the new equipment mechanism (sliding mechanism) install on mounted on the road surface. Thus if the system is installed at the entrance and exit of the parking areas, such as malls, hospitals, airports and others, then the equipment will obtain energy continuously from the passing vehicles. In a more massive and widespread implementation, this equipment has the potential to reduce the use of electricity sourced from fossil fuel energy.

II. THEORETICAL BACKGROUND

MEHU presented in this paper uses a rack and pinion mechanism to convert translational movements into rotational. The mechanical part of the harvesting unit is shown in Fig. 1. The dimension and rotational (angular) speed of the flywheel in the mechanical system of the MEHU are designed based on the safety criteria. In order to operate safely, the mass and rotational speed of the flywheel cannot exceed a certain value [19, 20].

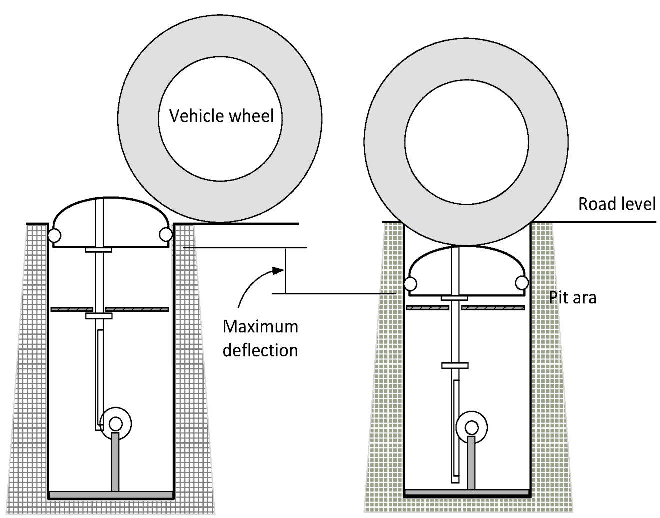

Fig. 1. Mechanical system of the MEHU

The entire MEHU unit consists of the mechanical unit and electrical units as shown in Fig. 2. When the vehicle passes at MEHU the vehicle's wheel will press the slider connected to the rack downward as shown in Fig. 1.

The rack will rotate the pinion mounted on the same shaft with the flywheel. When the vehicle's wheels pass the MEHU slider, the slider will displace downward for 12 cm (0.12 m). Assuming the weight of the vehicle is evenly distributed at the front and rear wheels, the amount of energy from the weight of the vehicle at the front wheels is calculated by Eq. 1.

$$U = \frac{W}{2} s \tag{1}$$

W is the weight of the vehicle, *N* and *s* is slider displacement, *m*.

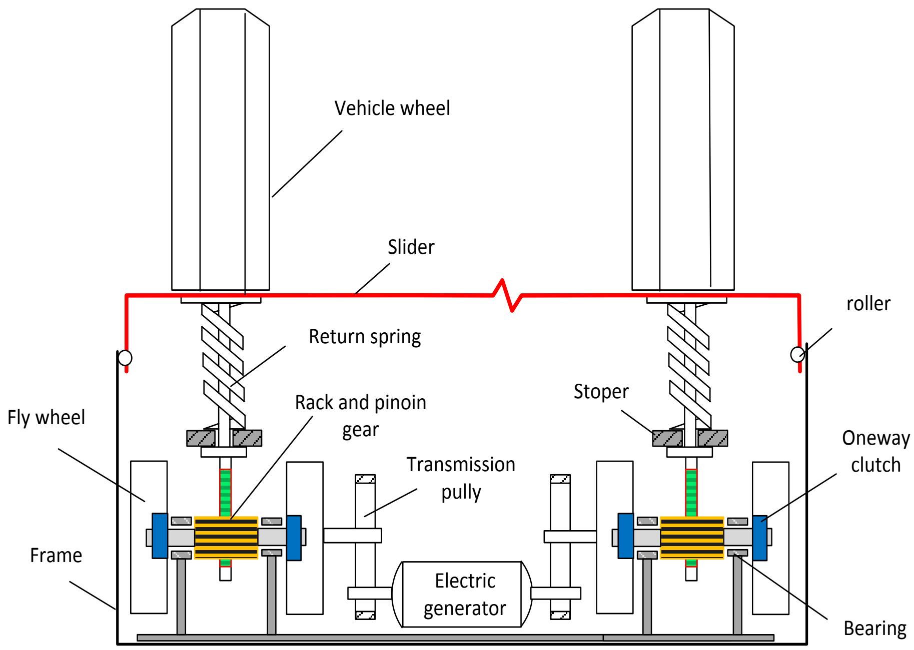

Fig. 2. MEHU

From the energy conservation law, the amount of energy received and the rotational speed of the flywheel can be calculated by Eq. 2.

$$\begin{aligned} U &= 0.5\mathrm{I}\omega^2 \\ I &= 0.5\mathrm{m}R^2 \\ \omega^2 &= \tfrac{2U}{l} \end{aligned} \tag{2}$$

I is mass moment of inertia of the flywheel, *R* radius of the flywheel (*m*), ω angular velocity of the flywheel, (rad/sec). The ratio of the pulley diameter on the flywheel shaft to the pulley diameter on the generator shaft as shown in Fig. 2 is 4 to 1. This pulley ratio is chosen to increase the rotational speed of the generator shaft four times faster than that of the flywheel shaft.

Considering any energy losses in the MEHU mechanical system such as friction between the slider and the frame, bearings, belt and pulley mechanism, the mechanical efficiency, ηm must be included in Eq. 2, and the equation becomes,

$$\omega^2 = \frac{2U}{I}\eta_m \tag{3}$$

Several values of mechanical efficiencies were taken into account to simulate the performance of the MEHU mechanical system.

III. Results and Discussion

This section discusses the results of the testing of the MEHU. The testing of the unit consists of two parts. The first testing is to measure the ability of the mechanical system of MEHU. This test is carried out to get the maximum rotation that the generator can get when the vehicle passes the MEHU. The second testing is to measure the ability of the generator to produce voltage and electric current under various loads and rotations. To facilitate the measurement of the generator performance, the testing of the electric generator of the MEHU is carried out at a constant rotation or constant speed.

A. Results of the MEHU Mechanical System Testing

Table I shows the mechanical system performances of the MEHU which were tested using three-vehicle weight, categorized as a small, medium, and large vehicle. The generator speeds (rotation) test results in Table I are the maximum speed that the generator can reach when the vehicles pass the MEHU. After the vehicles pass the MEHU, the generator rotation will decrease until finally, it stops. The maximum speed of the generator is obtained based on a pulley diameter ratio of 4 to 1 as shown in Fig. 2.

TABLE I
PERFORMANCE OF MEHU MECHANICAL SYSTEM

No.	Mass of vehicle (kg)	Weight of vehicle (N)	Generator rotation (rpm)	
			Simulation	Test Results
1	Small (1300 kg)	12,740	2589	2500
2	Medium (1700 kg)	16,660	2961	2890
3	Large (2000 kg)	19,600	3211	3140

Table I shows the MEHU's test results that represent the ability of the MEHU mechanical system to rotate the electric generator. The MEHU mechanical system based on three vehicle masses is able to produce generator rotational speed from 2500 rpm to 3140 rpm. This rotation range corresponds to the rotation range required by the MEHU electric generator.

Fig. 3 shows the simulation of MEHU's ability to rotate an electric generator. Simulations carried out with mechanical efficiency of 70%, 60%, and 50% respectively. The test results of the generator speed approach the generator speed simulation with 60% mechanical efficiency. The MEHU mechanical system test results indicate that it is still possible to improve the MEHU design so that its mechanical efficiency can be improved.

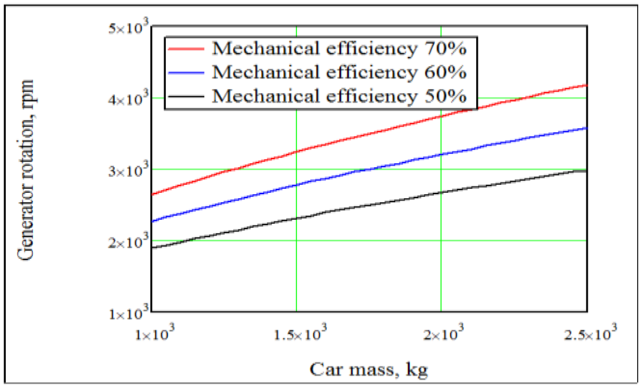

Fig. 3. Simulation of MEHU's ability to rotate the electric generator

B. Results of the MEHU Electric Generator Testing

MEHU electric generator testing is carried out at constant speed (constant roration) with various electric loads using LED lamps. The testing of electric generators at constant rotation is carried out to facilitate an easy measurement. When testing the electric generator at changing speed (based on the transient movement of the slider mechanism of the MEHU), the voltage and current measuring devices cannot read the data properly. Characteristics of measuring instruments used in this experiment (volts and amperes meters) can only read data properly when a condition or generator speed is steady.

The ability or performance of the MEHU electric generator is expressed in terms of voltage and current curves in the following figures. The electrical load is obtained or taken from LED lights consisting of 8, 6, and 4 lamps arranged in series to produce a voltage of 24, 18, and 12 volts respectively, to match the voltages generated by the electric generator.

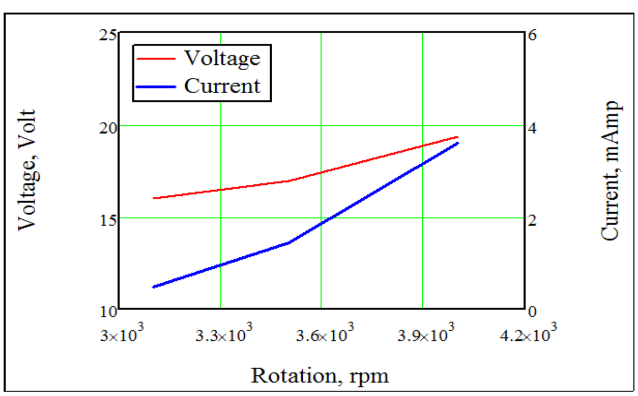

Fig. 4. Voltage and current taken from load of 8 LED lamps at various generator rotation (rpm)

Fig. 4 is the performance of the electric generator with a load of 8 LED lamps (24 volts). Rotation range starts from 3100 rpm, 3500 rpm to 4000 rpm, the resulting voltages start from 16 volts, 17 volts to 19.4 volts, with the resulting currents, are 0.48 mAmp, 1.43 mAmp to 3.6 mAmp respectively.

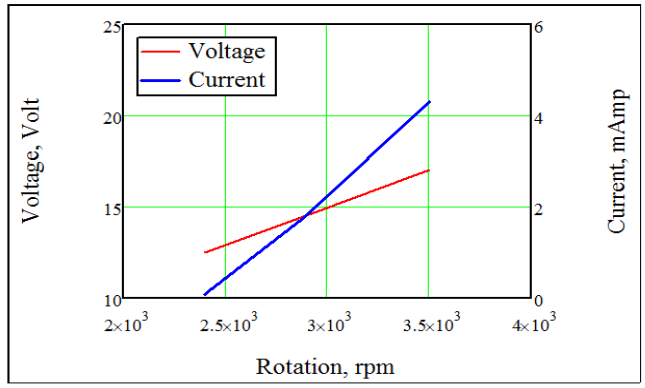

Fig. 5. Voltage and current taken from load of 6 LED lamps at various generator rotation (rpm)

Fig. 5 is the performance of the electric generator with a load of 6 LED lamps (18 volts). The rotation range starts from 2400 rpm, 2900 rpm to 3500 rpm; the resulting voltages start from 12.5 volts, 14.5 volts to 17 volts, with the resulting currents are 0.1 mAmp, 1.8 mAmp to 4.3 mAmp respectively.

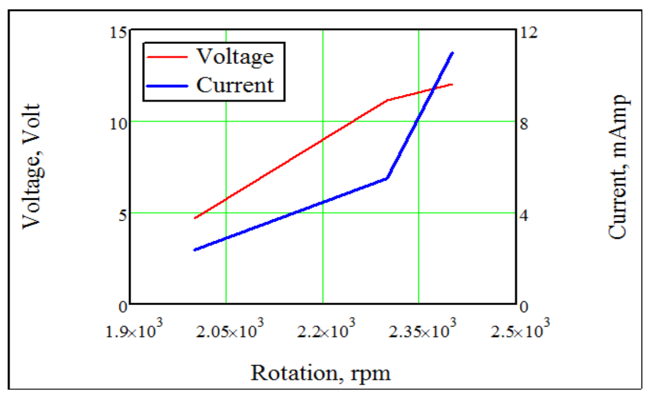

Fig. 6. Voltage and current taken from load of 4 LED lamps at various generator rotation (rpm)

Fig. 6 is the performance of the electric generator with a load of 4 LED lamps (12 volts). The rotation range starts from 2000 rpm, 2300 rpm to 2400 rpm; the resulting voltages start from 4.7 volts, 11.2 volts to 12 volts, with the resulting currents are 2.4 mAmp, 5.5 mAmp to 11 mAmp respectively.

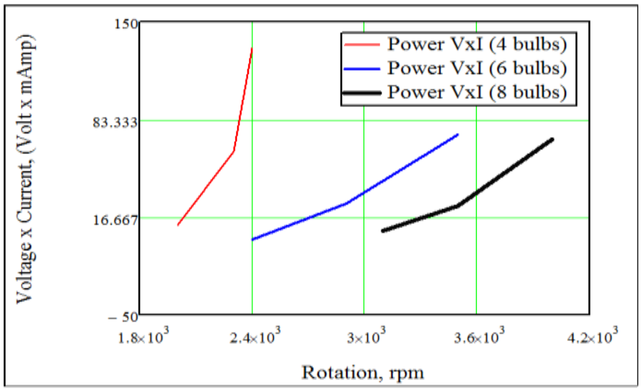

Fig. 7. Voltage and current taken from load of 4, 6 and 8 LED lamps at various generator rotation (rpm)

Fig. 7 shows the power curve that can be produced by the electric generator as a function of generator rotation, according to the load taken from several LED lamps being tested, namely 12 volts, 18 volts, and 24 volts. To store the electric power generated by the electric generator either a 12 volts battery or a 24 volts battery can be chosen. Based on the generator performance curves shown in Fig. 4 to Fig. 7 show that the mechanical system of the MEHU is able to rotate the electric generator to produce voltages and electric currents which are able to supply electrical power to power the LED lights.

C. Constraints During the Experiments

Some obstacles arise during the experiments. The first obstacle is the onset of friction between the slider and vertical frame of the MEHU mechanical system when the slider moves downward. When the car passes the MEHU, the slider cannot directly move down but swipe the MEHU vertical frame. This impedes the linear motion of the slider and reduces the ability to give maximum rotation generated by the MEHU mechanical system. This first obstacle can be overcome by adding a roller on the slider side. The roller added on the side of the slider can reduce significantly the friction between the slider and vertical frame of the MEHU and at the time it will improve and facilitate the linear motion of the mechanical system.

The second obstacle is the inability of the measuring devices to read data (voltage and current) when the generator speed or rotation is changing (transient rotation), so the voltage and current data can not be captured. During testing the electric generator using transient rotation, the LED light (as an electric load) turns on when the generator rotates at maximum rotation until a few moments before the rotation stops. This shows that the MEHU is able to produce electrical energy in transient or changing rotation even though the measuring devices can not display the voltage and current. But how much the voltages and currents generated, they can not be read by measuring devices. The voltage and current measuring devices capable of reading transient loads are needed to read data.

D. Further Experiments

Further experiments must be carried out to explore the capability of the MEHU being operated under different operating conditions. The first experiment will be conducted is to test the ability of MEHU to produce electric power while the electric generator is operated under changing speed (transient rotation). The following experiment is to determine how many cars per hour that must pass through MEHU to produce economical and sufficient electric power to be stored in batteries.

VII. CONCLUSION

The design of the MEHU is capable of producing rotation or speed accordingly to produce sufficient electrical energy by utilizing the weight of the vehicle. Thus the MEHU can be used as an alternative way to produce small-scale electrical energy. The MEHU mechanical system test results indicate that it is still possible to improve the MEHU design so that its mechanical efficiency can be improved. The mechanical efficiency achieved by MEHU is about 60%.

The weight of various vehicles parked in the urban parking areas with a mass of 1300 kg, 1700 kg, and 2000 kg, respectively, are capable of producing a maximum MEHU rotation of 2500 rpm, 2890 rpm, and 3140 rpm. Thus the use of vehicle weights as a driving source of the MEHU to supply the electricity needs by the portal gate system is appropriate. The MEHU testing with constant speed using various loads of LED lamps with 24 Volt, 18 Volt, and 12 Volt voltage produces a power of 19 Volt x 3.6 mAmp (4000 rpm), 17 Volt x 4.3 mAmp (3500 rpm), and 12 Volt x 11 mAmp 2400 rpm) respectively.

VI. ACKNOWLEDGMENTS

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Declaration of Competing Interest

The authors declare that there is no conflict of interest.

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