PERFORMANCE OF ENERGY REGENERATIVE SUSPENSION SYSTEM THROUGH LABORATORY TESTING

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ABSTRACT

Conventional suspension system provides ride comfort to passengers by absorbing the vibration and dissipating it to the environment. This paper aims to investigate the enhancement of regenerative suspension system (EReSS) in order to harvest energy from the vibration of vehicle suspension system. The system has been tested and accomplished utilizing laboratory test rig. The output voltage harvested up to 32.76 V at 400 windings. In accordance to the obtained results, it is observed that the proposed system can minimize the energy wastage due to the vibration and produces effective electrical and electronic utilizations. In addition, the output voltage of the EReSS can be affected by the number of windings of the coil and diameter of the coil. The EReSS has been proven successful in harvesting energy; therefore, it can be used on hybrid and electric vehicle to improve efficiency of the vehicle and reduce fuel consumption.

KEYWORDS: *Regenerative suspension; energy harvesting; energyefficient vehicle*

1.0 INTRODUCTION

Vehicle suspension system can be defined as a system that connects the vehicle tires and springs to vehicle wheels in order to enable vehicle motion. The main function of suspension system is to act as a mechanical system which isolates the sprung mass and communicate with un-sprung masses of the vehicle and offers a convenient vehicle stability The sprung mass is referred to as the vehicle body, while the un-sprung mass is refered to the vehicle wheel (Abdullah et al., 2015a). The vehicle suspension system comprises of damper and spring. The damper is utilized to absorb the vibration generated and distributes the energy to the environment. This type of energy can be harvested with the assistance of a modified suspension system called the energy regenerative suspension system. In addition, the fuel consumption can be minimized by utilizing the regenerative shock absorber (Tang and Zuo, 2011) since the gained energy is utilized to charge the battery of the vehicle as well as to enable the battery to start up instead of powering up the vehicle battery using alternator (Patil and Gawade, 2012). Gysen et al., (2011) reviewed research activities in the field of regenerative suspension system which pointed that most of the studies is to produce improvement in the suspension system (Gysen et al., 2011).

Various researchers have paid much concern about the field regenerative suspension. a study (Zuo and Phang, 2013) concentrates on obtaining a comprehensive evaluation of

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the available power to be harvested on the vehicle suspension system in order to gain an average power of100W to 400 W. A testing experiment at 60 mph on mid-size vehicle suspension system was conducted to obtain the results of the study. Based on the results obtained, it shows that the road roughness, tire stiffness and vehicle driving speed influenced the harvested power within the energy regenerative suspension system. In addition, the suspension stiffness, damping coefficient and vehicle mass are not much sensitive in comparison to other parameters of the suspension system. In conclusion, the testing of this study was made in better and average roads in order to emphasize accurate results.

In his study, Hedlund (2010) introduced a hydraulic vehicle suspension system where the system was tested in the laboratory with the help of utilization all-terrain vehicle (AVT). During laboratory testing, it was found that the produced voltage is 6.13 V while on the road it was 0.62 V. Usually, the regenerative suspension system is manually operated during laboratory testing. However, the system can be operated in automotive mode as well in order to produce less voltage of about 0.2 V. Hence, the results obtained in this study show that the hydraulic regenerative shock absorber can produce electrical energy.

Khosnoud et al. (2013) have proposed a new suspension energy harvesting approach which is the regenerative force actuators. This approach can gain maximum harvested power ranging from 984.4 W and 1106 W for every suspension system on a vehicle. In addition, this study utilized a frequency value ranging between 0.5 Hz to 20 Hz to be used in the testing experiment. Moreover, the study shows that, the value of harvested power can be raised to big value by keeping the actuator value at constant value.

Moreover, in a research by Li et al. (2011), a shock absorber with mechanical motion rectifier to be utilized for energy harvesting is built. The designed shock absorber was built in order to enhance the energy harvesting efficiency and reduce the impact forces from the oscillation. This study utilized the mechanical motion rectifier (MMR) in order to operate as converter, which converts the oscillatory vibration to be uni-directional rotation of the generator. In order to verify the operation of MM R, a testing experiment was done which obtained better results than conventional regenerative shock absorbers at high frequency with 60 % efficiency. Apart from that, another road test has been achieved on the MMR which produced 15W of electric power with driving speed of 15 mph on a smooth paved road.

Continuing in the same context, a study (Li and Zuo, 2014) has introduced a basic electromagnetic regenerative shock absorber. The study shows that the proposed system can recover the kinetic energy from the vehicle vibration and utilize a linear or rotational electromagnetic generator to convert the kinetic energy to electrical energy. In addition , this proposed system is able to improvevehicle fuel efficiency in which the results obtained in this study show that the peak power generated by the proposed system is about 58.2 W and 67.5 W for road testing of a sport utility vehicle (SUV) with a speed of 20 mph and 30 mph, respectively.

However, the improvement that has been accomplished still does not suffice the requirements of the commercial applications (Lin et al., 2010). Hence, the requirement for producing an improved and sufficient regenerative suspension system is very important in order to fit the power demand and produce the required enhanced final output.

Nowadays, most researchers and industries pay a lot of attention to electromagnetic energy regenerative suspension system due to its simplicity and low cost (Longxin and Xiaogang, 2010). Such system simply operates by utilizing a relative gap motion of the suspension system on a vehicle. Whenever the vehicle moves in irregular road surface, the vehicle suspension reciprocates and the reciprocating of the suspension activates the electromagnetic energy regenerative suspension system and the magnet moves upwards and downwards. Due to the movement of the magnet, it will cut the magnetic induction lines and generateelectricity in the coil which is winded along the magnet movement direction (Pei, 2010).

2.0 METHODOLOGY

In this section, the design flow of the designed system is discussed and presented in details. The system was done in laboratory and the flow of the system is illustrated as follows:

2.1 Conceptual Design

First of all, the energy regenerative suspension design (EReSS) is opted, in which the design is selected by analyzing several concepts that have been previously proposed. The opted design is considered as the best concept that can give out the highest voltage reading theoretically. In addition, the opted EReSS concept is easier to be fabricated and applied. This concept utilizes a single barrel housing that contains all the important part for the electromagnetic regenerative suspension system. The system is retrofit that will be attached on the original suspension system of a vehicle (Abdullah et al., 2015b).

2.2 Fabrication of EReSS

The concept design of the EReSS is selected properly and then fabricated. The fabrication process is achieved by following the design concept that has been drawn on computer-aided-drafting (CAD) software. The CAD drawing is built to ensure the product component compatibility to each other and ease the process of fabrication. Figure 1 shows the components of EReSS, while Figure 2 shows the EReSS of fabricated full assembly (Jamil et al., 2015).

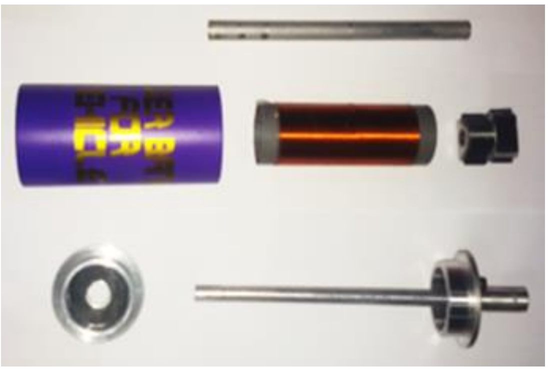

Figure 1. Fabricated components of the EReSS

Figure 2. Fabricated of EReSS assembly view

2.3 Parameters of EReSS

The improvement of the regenerative suspension system has a significant role in the obtained required power. In addition, the EReSS parameters play an important role in the power productivity. The experiments were carried out by changing each parameter in order to choose the most effective parameter. The test rig frequency was set from 10 Hz to 40 Hz and the number of windings for each test was set to be 400, 250 and 100. This was done in order to compare different voltage reading at each number of windings. The diameter of the coil wire was set to be 0.29 mm, 0.4 mm and 0.8 mm. and the standard NdFeb (grade N35) magnet was used with magnetic flux density of 1.2 T. Table 1 shows the summarized parameters used for the EReSS.

Table 1. Summarized parameters for the EReSS

Parameter	Value
Diameter of coil (mm)	0.29, 0.4, 0.8
Number of winding	400, 250, 100
Magnetics flux density (T)	1.2
Frequency of test rig (Hz)	10, 20, 30, 40

2.4 Experimentation of EReSS

The experimental testing of EReSS was done in the laboratory test rig at the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) The test rig utilized electric motor and crank mechanism to produce reciprocating force for the test. The frequency of the motor was set according to the required frequency and to change the frequency entered to the device periodically at each experience. The test rig with the EReSS in the laboratory is shown in Figure 3. When moving the plate on vertical axis, the plate was attached to the side round column with bearing and joint. Then, the assembly acted as slider so that the plat moved freely with low friction. The suspension with magnet and coil module was attached to the upper and lower plates of the test rig with mountings.

The EReSS prototype can generate electricity due to induction of vertically moving magnets and magnetic fields through coils. However, the inductance generates AC current while the storage most requires DC current. Therefore, a rectifier bridge is required to convert AC to DC current. The rectifier bridge was installed in a simple electric circuit. The output voltage of the EReSS wasrecorded by using the data acquisition (DAQ) system, which consists of Lego Mindstorms Ev3 combined with voltage measuring sensor as shown in Figure 4. The reading was recorded for all the test done on the test rig with different parameters set up. The first experiment was performed for different number of windings diameters of the coil wire and with different frequency.

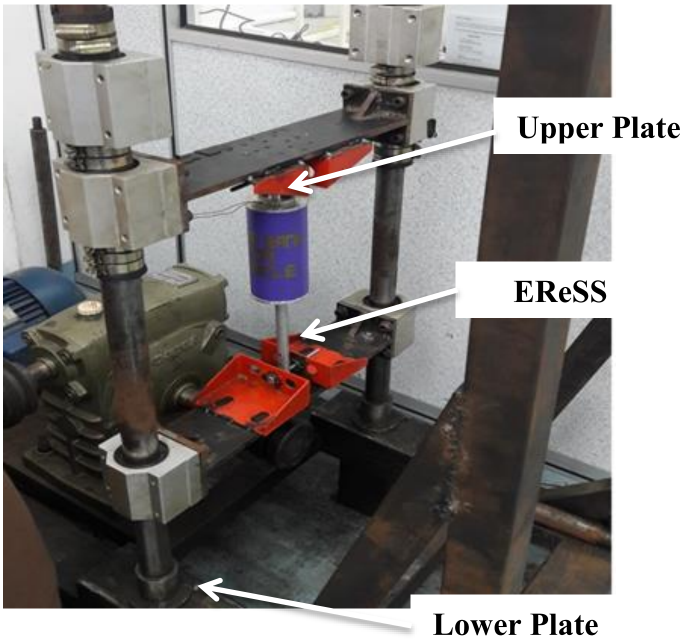

Figure 3. EReSS system fixed on the test rig in laboratory

Figure 4. Data acquisition (DAQ) system

3.0 RESULTS AND DISCUSSION

The energy regenerative suspension system (EReSS) is fabricated and tested in the laboratory. The design of the EReSS is retrofit which does not disturb the original suspension system of the vehicle. This EReSS can function automatically by following the suspension movement. The experiment was done on a test rig in the laboratory. The results of the EReSS test were recorded and analyzed. The results of the each test are shown in the Figures 5, 6, 7, and 8, which illustrate the results in graphical manner as below. In these figures, the fluctuating voltages are captured. The results of the tests aresummarized in Table 2 and Figure 9 illustrates the results in graphical form.

The voltage reading of the EReSS is affected by number of winding and diameter of the coil. The results show that the voltage reading decreases when the number of windings is reduced ,where the highest voltage reading of the test is 32.76 volt at 40 Hz for 0.29 mm coil wire diameter, while at 0.4 mm coil wire diameter the maximum voltage is 30.61 volt with 30 Hz. Apart from that, the voltage reading is 30.59 volt at 40 Hz for 0.8 mm coil wire diameter as shown in Figure 5 and Table 2. It can be observed that 40 Hz frequency produces the highest voltage output.

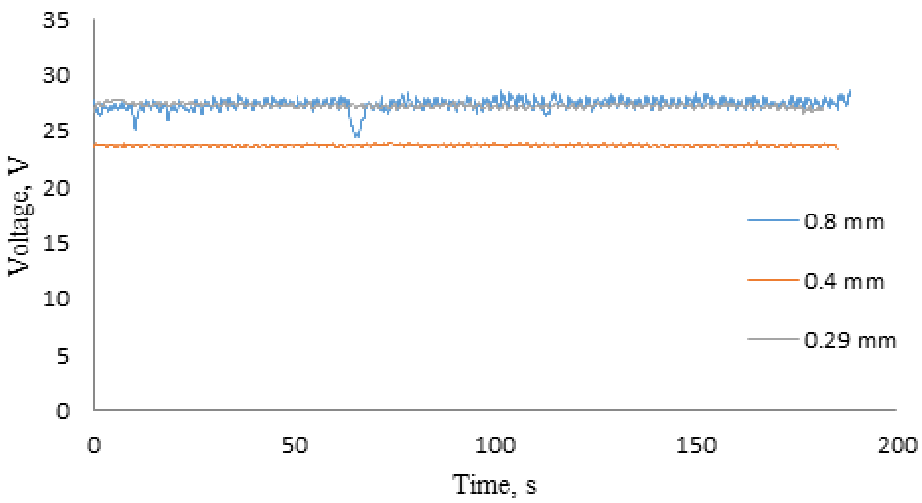

Figure 5. EReSS test with 10 Hz frequency

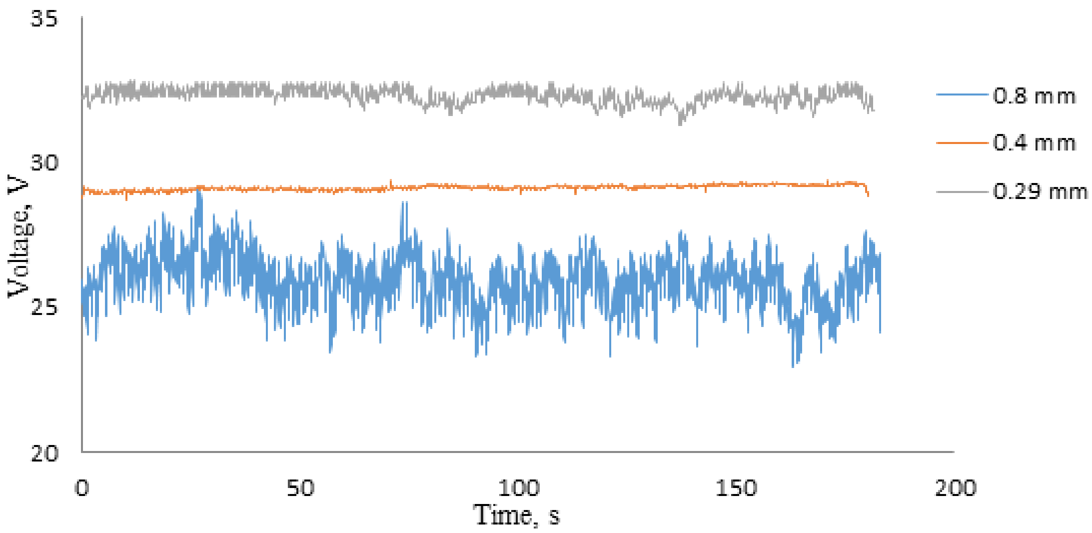

Figure 6. EReSS test with 20 Hz frequency

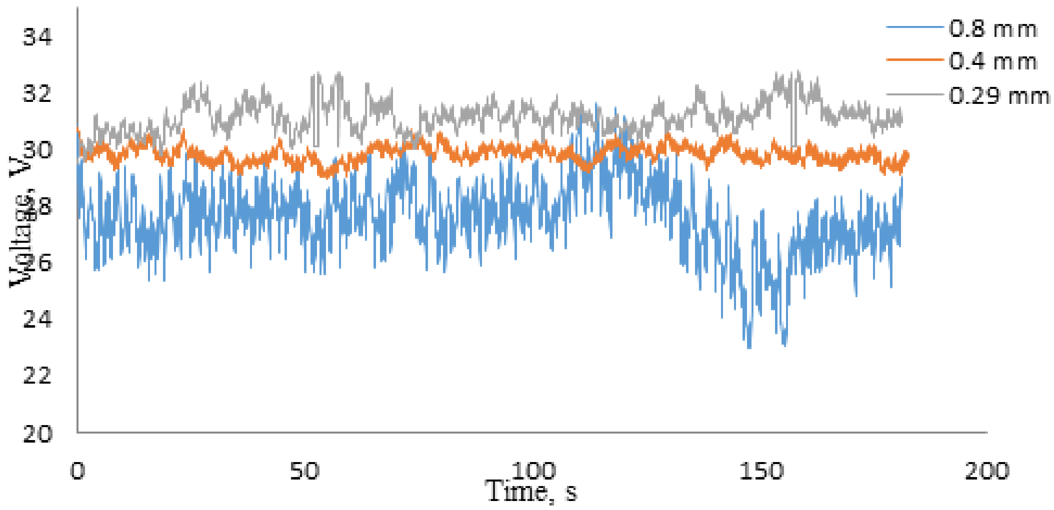

Figure 7. EReSS test with 30 Hz frequency

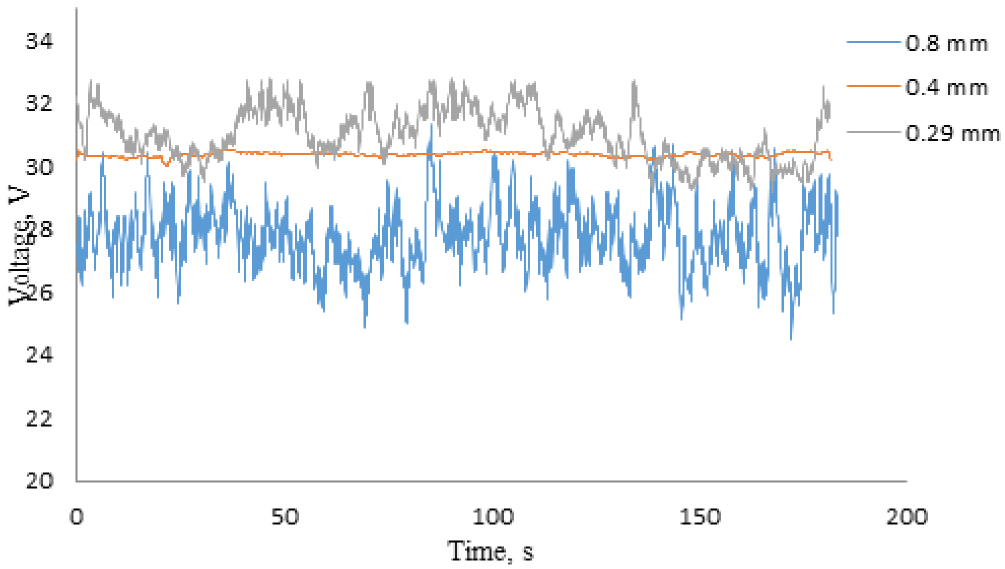

Figure 8. EReSS test with 40 Hz frequency

Apart from that, resonance usually occurs at 40 Hz frequency which is able to produce the highest voltage output, while at 10 Hz frequency the generated voltage is very low. This occurrsbecause the velocity is very slow at this frequency in comparison to other frequency values, and the magnetic induction is very slow as well.

Theoretically at resonance, large amount of power is consumed in order to maintain the vibration; hence the EReSS can be utilized as back up power to operate the vehicle . Operating at rosanace frequency can be considered as a feature for EReSS due to the high amplitude which makes the suspension experience forceful movements that maximize the voltage output of the system. Apart from that, increasing the frequency of the motor for the test rig can cause the oscillation of the test faster in which ,when the oscillation is faster, the higher the voltage is produced by the EReSS due to the higher magnetic induction as the coil cuts the lines of the flux .
As observed earlier, the EReSS can produce voltage , and this produced voltage can be utilized in the vehicle electrical and electronic system ,such as operating the electronic computer unit (ECU) and lighting. EReSSs is advised to be used in EEV vehicle or hybrid vehicle due to its ability to charge the battery and reduce the requirement of alternator ;hence , by reducing the demand on the alternator, it can reduce the engine load and at the same time it will reduce the fuel consumption of the vehicle itself. Not only that, the EReSS is self -operated without demanding for any other power source.
In addition to that , the output voltage can be improved by enhancing the material of the electromagnetic system of the EReSS such as using higher magnetic flux density magnet which is rare earth permanent magnet NdFeb (grad N35). The magnetic flux density for rare earth permanent magnet NdFeb (grad N35) is 1.2 T, so that, by using high magnetic flux densityin EReSS it will produce high magnetic field and increase the output voltage of the EReSS. The equipment used for the EReSS test can be improved by using a more suitable equipment which is DAQ system that can record all the data to improve the data recording accuracy.

Table 2. Voltage reading for the EReSS with different number of windings and coil wire diameters

No of windings	**Coil wire diameter (mm)**	**Frequency setting (Hz)**			
		10	**20**	**30**	**40**
		Voltage (V)			
400	0.29	27.86	32.72	32.74	32.76
250	0.4	24.05	29.26	30.61	30.48
100	0.8	28.41	28.59	30.66	30.59

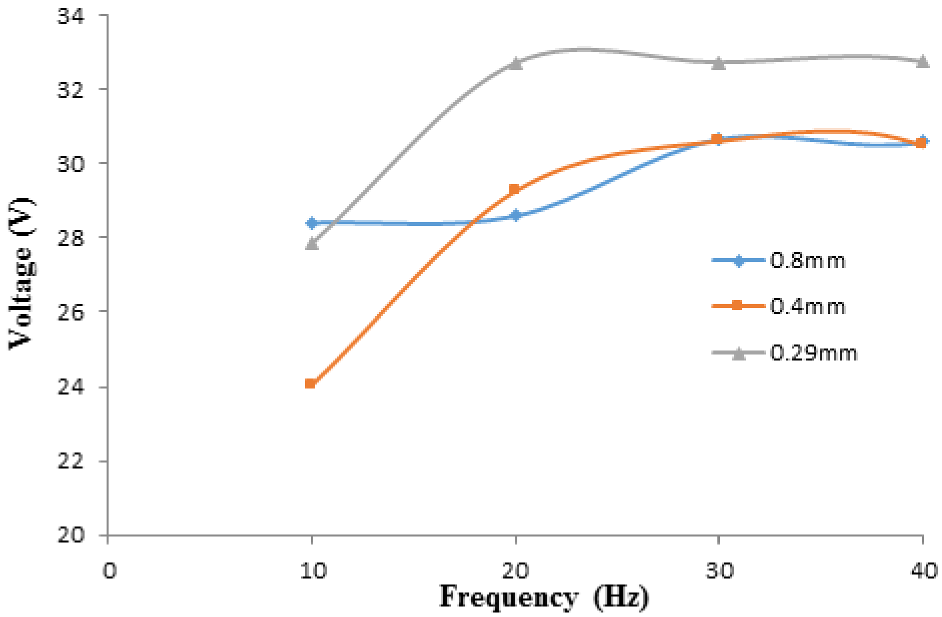

Figure 9. EReSS tested with different diameter of coil wire

4.0 CONCLUSION

In conclusion, this paper focuses on the development of a harvesting device for suspension system. The proposed suspension system utilizes the EReSS and was tested using the laboratory test rig. According to the test results, it is observed that the maximum voltage reading for parameters variation for the system testing is 32.76 V. In addition, the output voltage could be enhanced by improving the materials utilized in the electromagnetic system of the EReSS. Measuring instruments must be used in order to read the value of frequency of the test rig so that the produced output voltage can be recorded with respect to frequency variation. Moreover, from the obtained results, it is noticed that the output voltage of the EReSS is affected by varying the number of windings and coil wire diameter. Apart from that, varying the frequency during the test also plays an important role in producing better performance of the system. Lastly, the proposed system utilizes the regenerative shock absorber to act as reduction tool of the fuel consumption in which the gained energy can charge the battery of the vehicle and help to start up the battery instead of using the alternator on the vehicle.

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