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FABRICATION AND TESTING OF ELECTROMAGNETIC ENERGY REGENERATIVE SUSPENSION SYSTEM

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Graphical abstract

Abstract

The world is demanding for alternative way of energy consumption for vehicle usage. The energy efficient vehicle (EEV) is one of the advancement for future land transportation that known as hybrid and electric vehicles nowadays. The vehicles use different energy other than fuel which is electric energy. This paper emphasizes the development of electromagnetic energy regenerative suspension system (EReSS) as a system that harvests energy from the vibration of vehicle suspension system. The harvested energy is converted to electrical energy for vehicle usage. A prototype of electromagnetic EReSS is fabricated and laboratory experimentation on test rig is conducted to test the voltage output. It is observed that the EReSS can harvest the wasted energy from the vibration and produce sufficient electric energy for the vehicle electrical and electronic usage. The number of windings of the coil and diameter of the coil affect the voltage output of the EReSS. The voltage output of the EReSS can be optimized by setting up the parameters. As the EReSS is proven to harvest energy, it can be used on hybrid and electric vehicle to improve the efficiency of the vehicle and reduce the fuel consumption.

Keywords: Energy regenerative suspension; hybrid; EEV; electric vehicle

Abstrak

Dunia sedang menuntut cara alternatif penggunaan tenaga untuk kegunaan kenderaan. Kenderaan (EEV) adalah satu kemajuan bagi pengangkutan darat di masa hadapan yang dikenali sebagai kenderaan hybrid dan elektrik. Kenderaan tersebut menggunakan tenaga yang berbeza dari bahan api iaitu elektrik. Kertas kerja ini menekankan pembangunan sistem suspensi regeneratif elektromagnet (EReSS) yang menuai tenaga daripada getaran sistem suspensi kenderaan. Tenaga yang dituai ditukarkan kepada tenaga elektrik untuk kegunaan kenderaan. Prototaip electromagnet (EReSS) telah direkabentuk dan ujian di makmal telah dijalankan untuk menguji voltan yang dihasilkan. Daripada pemerhatian, EReSS dapat menuai tenaga yang terhasil dari getaran dan menghasilkan tenaga elektrik yang mencukupi untuk kegunaan elektrikal dan elektronik pada kenderaan. Bilangan lilitan dan diameter gegelung mempengaruhi penghasilan voltan oleh EReSS. Voltan yang dihasilkan boleh dioptimumkan dengan mengubah pembolehubah. EReSS telah dibuktikan kebolehannya untuk menuai tenaga dari getaran, ia boleh digunakan pada kenderaan hybrid dan elektrik untuk meningkatkan kecekapan kenderaan dan mengurangkan penggunaan bahan api.

Kata kunci: Sistem suspensi regeneratif; hybrid; EEV; kenderaan elektrik

1.0 INTRODUCTION

Suspension system of a vehicle functions as a mechanical system that supports the sprung and interacts with un-sprung masses of a vehicle. The sprung mass is the vehicle body and the un-sprung mass is the wheel. It isolates the vehicle body from road disturbances and helps the wheel to hold on various road surfaces [1-3]. There are bumpy roads, acceleration or reduction of the driving speed and the operations of the steering wheel when driving a vehicle [4]. This behavior cause relative shock between the sprung mass and un-sprung mass. The shock is a part of mechanical power that can be recycled [5]. The suspension system provides better road handling for passenger comfort [3, 6]. The main element in the suspension system is the damper and spring. The damper is the one that absorbs the vibration produced by the road irregularities and dissipates the energy to the surrounding. This energy can be harvested with a modification of the suspension system called energy regenerative suspension system [3]. The research about vibration harvesting on suspension was started about two decades ago. It was an approach to improve fuel consumption of land vehicle [7]. Regeneration of waste energy is one of the important elements in mechanical engineering fields [8].

There are several studies and researched on the regenerative suspension system and improvement on the designed system but until now the development is still far away from the demands on the commercial applications. There are only some researchers that discovered and made a concrete achievement in specific test [9].

Zuo and Zhang [10] made a research about a comprehensive assessment of the power that is available for harvesting on the vehicle suspension system and get about 100 W to 400 W average powers can be harvested. The result is obtained by doing experiment on a mid size vehicle suspension system tested at 60 mph. It stated that the road roughness, tire stiffness and vehicle driving speed affected the power harvested through the energy regenerative suspension system. The suspension stiffness, damping coefficient and vehicle mass are not as sensitive as the others that are stated. The test was made on good and average roads.

Hedlund [11] proposed a hydraulic regenerative vehicle suspension that is tested on the laboratory and all-terrain vehicle (ATV). In the laboratory, the voltage produce is 6.13 V and on road is 0.62 V. The laboratory testing of the regenerative suspension system is manually controlled, however with automatic control; the voltage produced is only 0.2 V. This result shows that the hydraulic regenerative shock absorber can generate electrical energy.

Khoushnoud *et al* [12] proposed regenerative force actuators for suspension energy harvesting. It gets maximum power values of power harvesting of 984.4 W and near to 1106 W for each of the suspension system on the vehicle. The frequency excited for the experiment is 0.5 Hz to 20 Hz. The value of the harvested power can be increased by the constant value of the actuator.

Li *et al* [13] designed a shock absorber with mechanical motion rectifier (MMR) for energy harvesting. The shock absorber was designed to improve the energy harvesting efficiency and reduce the impact forces from the oscillation. The MMR function is to convert the oscillary vibration to be unidirectional rotation of the generator. Experimental testing of the MMR was done and 60% efficiency at high frequency was achieved and it is better than the conventional regenerative shock absorbers. A road test was also performed on the MMR and gave out 15 W of electric power. The driving speed of the test was 15 mph on a smooth paved road.

Li and Zuo [14] proposed a simple electromagnetic regenerative shock absorber. They stated that the system recovered the kinetic energy from the vehicle vibration and used a linear or rotational electromagnetic generator to convert the energy to electrical energy. This system can improve the fuel efficiency of the vehicle. The results showed that the peak power generated by the 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.

Electromagnetic energy regenerative suspension system is popular among the researchers since the system is simple and low cost. It attracts researchers to replace the current passive, semi-active and hydraulic suspension system because it will improves the vehicle efficiencies [15-17]. The system functions by using relative gab movement of the suspension system on a vehicle. When the vehicle moves in irregular road surface, the vehicle suspension reciprocates. The reciprocating of the suspension operates the electromagnetic energy regenerative suspension system and the magnet moves upwards and downwards. The movement of the magnet will cut the magnetic induction lines and generates electricity in the coil that winded along the magnet movement direction [18-20].

This paper introduces a new design and development of electromagnetic regenerative suspension system by designing a low cost concept of system, fabrication and testing of prototype. The other method of harvesting suspension vibration is high in cost. The new system will use less cost of production with the same function and acceptable harvesting result.

2.0 METHODOLOGY

2.1 Conceptual Design

Computer aided design (CAD) software is used for the drawing of the energy regenerative suspension system (EReSS). This is to ensure that the component can be fabricated with accurate dimension. Accurate dimension helps the component of the EReSS can be assembled together. Several concepts are designed on the CAD software and only one concept is chose for the fabrication. The chosen concept is shown in Figure 1. Material used for each of the part on the EReSS is different depending on the part function. The EReSS designed is retrofit which does not disturb the present vehicle suspension system. It is also functions automatically without any other power source so that the EReSS can give out maximum electrical generation for the vehicle usage.

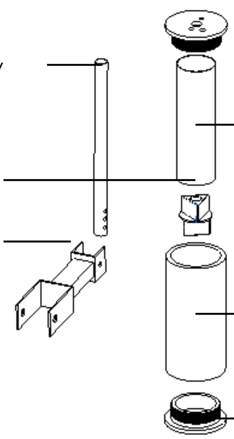

Figure 1 Chosen concept of EReSS

2.2 Fabrication of EReSS

The EReSS is fabricated according to the CAD drawing. The component is fabricated part by part. Material used by the EReSS is set depending on the strength needed by each component function. Table 1 shows the material used for the fabrication of EReSS.

Table 1 Material used for EReSS fabrication

Component	Material
Housing	Teflon
Shaft	Aluminum
Setter	Metal
Magnet holder	Aluminum
Caps	Steel
Bracket	Metal

The aluminium and steel are used to prevent the component from rust. Rust decreases the efficiency and increases the maintenance of the EReSS. Teflon is used for the housing because it can stand high temperature as reciprocating part will produces friction. Figure 2 shows the fabricated EReSS. Figure 3 shows the component of the EReSS.

Figure 2 Fabricated EReSS

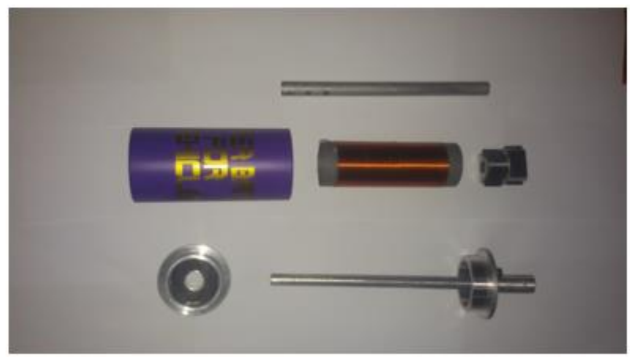

Figure 3 Fabricated components of the EReSS

2.3 Parameters of EReSS

The parameter of the EReSS is then set for the testing. The maximum number of windings for the coil of the EReSS is calculated using Eq. (1).

$$N = \frac{L}{D_c} \tag{1}$$

Where N stands for number of windings, L stands for the length of the setter (m), and D_c stands for the diameter of the coil, (m).

The frequency of the test rig is set from 10 Hz to 50 Hz. The number of windings for each test is set to 400, 250 and 100. This is done for comparing the voltage reading different at each number of windings. The diameter of the coil is set to 0.29 mm, 0.4 mm and 0.8 mm. The standard ferrite magnet is used with magnetic flux density of 0.2 T. Table 2 shows the summarized parameters used for the EReSS.

Table 2 Summarized parameters for EReSS

Parameter	Value
Diameter of coil (mm)	0.29, 0.4, 0.8
Number of winding	400, 250, 100
Magnetix flux density (T)	0.2
Frequency of test rig (Hz)	10, 20, 30, 40, 50

2.4 Experimentation of EReSS

The EReSS is tested on the laboratory test rig. The test rig uses DC motor and crank mechanism to produce reciprocating force for the test. The frequency of the motor can be set according to the required frequency. The test rig with the EReSS on the laboratory is shown in Figure 4. Voltage output of the EReSS is recorded by using multimeter as shown in Figure 5. The reading is recorded for each of the test done on the test rig with different parameters set up [21]. The first experiment is performed for different number of windings and followed by the experiment with different diameters of the coil. If the number of windings is too small, small voltage output is produced but it cannot be read by the multimeter.

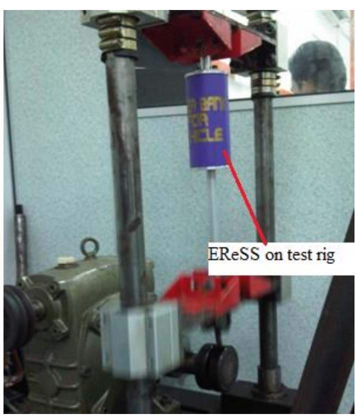

Figure 4 Test rig for the EReSS testing in laboratory

Figure 5 Voltage recording using multimeter

3.0 RESULTS AND DISCUSSION

The result of the test is hown in Table 3 and Table 4. Figure 5 and Figure 6 illustrates the results in a graphical manner.

Table 3 Voltage reading for the EReSS with different number of windings

	Voltage (V)		
Number of winding/ Frequency (Hz)	400	250	100
10	0.82	0.43	0.27
20	2.06	1.98	1.25
30	1.64	2.01	1.56
40	3.03	2.24	1.98
50	1.40	1.15	0.73

Table 4 Voltage reading of the EReSS with different diameter of the coil

	Voltage (V)		
Diameter of coil (mm)/ Frequency (Hz)	0.29	0.4	0.8
10	0.82	0.04	0.03
20	2.06	0.07	0.02
30	1.64	0.09	0.02
40	3.03	0.16	0.02
50	1.40	0.09	0.01

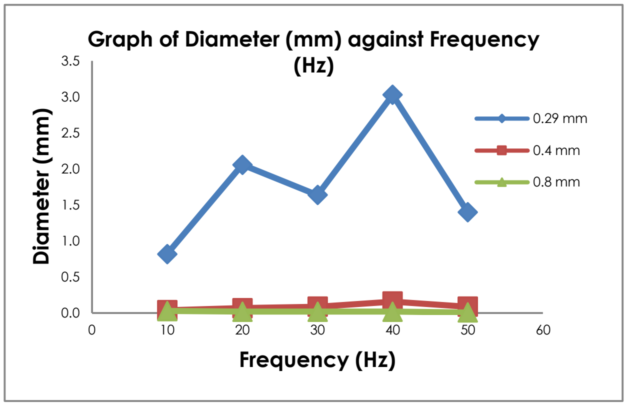

Figure 6 Graph plot of EReSS test with different number of windings

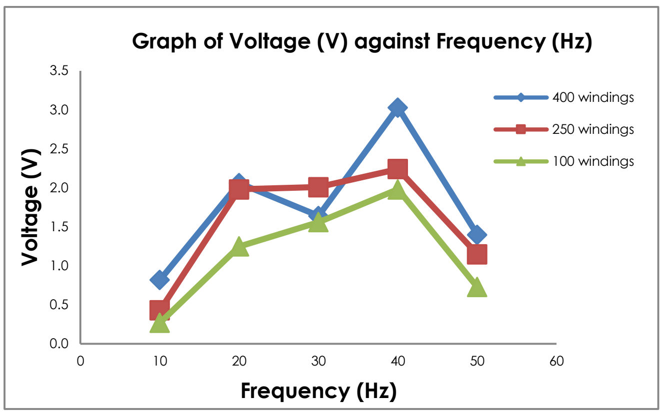

Figure 7 Graph plot of EReSS test with different diameter of coil

The number of winding and diameter of the coil affected the voltage reading of the EReSS. The results show that the voltage reading is decreasing when the number of windings is reduced. The highest reading of the test is 3,03 V at 40 Hz for 0,29 mm diameter, 2.24 V for 0.4 mm and 1.98 V for 0.8 mm diameter. It can be observed that 40 Hz frequency produces higher voltage output from the test.

Resonance occurs at frequency of 40 Hz that generates highest voltage output. The lowest value of voltage generation is in the frequency of 10 Hz. This is because the velocity is slowest among others and the magnetic induction is lowest. At 50 Hz, the voltage output decreased instead of increased due to the fact that 40 Hz is the peak amplitude for the designed EReSS.

Theoretically, higher power consumption is needed at the resonance to sustain the vibration. So, EReSS can be the backup power for the vehicle. It is an advantage for the EReSS at the resonance frequency which is high on the amplitude and the suspension experiences forceful movements that maximize the voltage output of the system. Increasing the frequency of the motor for the test rig caused the oscillation of the test faster. As the oscillation is faster, the higher the voltage produced by the EReSS due to the higher magnetic induction as the coil cut the lines of the flux at a faster rate.

Since EReSS can generate voltage, it can be used on the vehicle electrical and electronic systems for applications such as the electronic computer unit (ECU) and lighting. It is an advantage for EEV or hybrid vehicles to charge the nattery of the vehicle and reduce the demand on the alternator. Reducing the demand on the alternator will reduce the engine load and at the same time it will reduce the fuel consumption of the vehicle itself. Other than that, the EReSS is self-operated without demanding any other power source.

The EReSS voltage output can be improved by changing the ferrite magnet with higher magnetic flux density magnet such as rare earth permanent magnet. High magnetic flux produces high magnetic field, and increases the output voltage of the EReSS. Other than that, the equipment used for the EReSS test can be upgraded by using more suitable equipment such as software and DAQ that can record all the data to improve the data recording accuracy.

4.0 CONCLUSION

The EReSS is fabricated and tested on the laboratory. The result shows that EReSS can generate electrical energy by harvesting the vertical vibration of suspension. The number of windings and coil diameter affected the voltage output. The higher the number of windings and smaller diameter of coil will give out higher voltage output of the EReSS. The frequency of the test is also plays important role in producing better performance. The EReSS can be used on hybrid and electric vehicles to increase the efficiency and reduce fuel consumption. Furthermore, it can help on charging the batteries of the vehicle. Other than that, the EReSS can reduce the work load on the engine because the alternator usage is reduced as the EReSS supplied alternative electrical energy to the vehicle.

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References

[1] Abdullah, M. A., Jamil, J. F., Mat Yamin, A. K., Mat Nuri, N. R. and Hassan, M. Z. 2015. *Vehicle Dynamics, Teaching and Learning Series*, Faculty of Mechanical Engineering, Module 10, Penerbit Universiti, Universiti Teknikal Malaysia Melaka.

[2] Abdullah, M. A., Jamil, J. F., Ismail, N., Mohammad Nasir, M.Z. and Hassan, M.Z. 2015. Formula Varsity Race Car - Roll Dynamic Analysis, *Proceedings of Mechanical Engineering Research Day 2015: MERD'15 2015*. 23-24.

[3] Abdullah, M. A., Tamaldin, N., Mohamad, M. A., Rosdi, R. S. and Ramlan, M. N. I. 2015. Energy Harvesting and Regeneration from the Vibration of Suspension System. *Applied Mechanics and Materials*, TransTech Publications. 699: 800-805. doi:10.4028/www.scientific.net/AMM.699.800.

[4] Abdullah, M. A., Salim, M. A. and Mohammad Nasir, M.Z. 2014. Dynamics Performances of Malaysian Passenger Vehicle, *Proceeding of International Conference on Automotive, Innovation and Green Energy Vehicle (AiGEV 2014)* Pahang, 26-27 August 2014, Malaysia, Organized by Universiti Malaysia Pahang, Paper ID: P027.

[5] Lin, X. and Xuexun, G. 2010. Hydraulic Transmission Electromagnetic Energy Regenerative Suspension and Its Working Principle. *2nd International Workshop on Intelligent Systems and Applications. IEEE*: Wuhan. 1-5.

[6] Abdullah, M. A., Abdul Kadir, F. A., Phuman Sigh, A .S., Ahmad, F. and Hudha, K. 2015. *Vehicle Control System, Teaching and Learning Series*. Faculty of Mechanical Engineering, Module 11, Penerbit Universiti, Universiti Teknikal Malaysia Melaka.

[7] Sabzehgar, S. and Moallem, M. 2012. *Regenerative Damping of a Suspension System Testbed. IEEE*. ISBN: 9781467301589.

[8] Zuscikova, M., Ioksik, M., Huertas, V.V. and Belavy, C. 2013. Adaptive Control Design for Vehicle Suspension. *International Conference on Process Control.* IEEE: Slovakia. 235-240.

[9] Lin, X., Bo, Y., Xuexun, G. and Jun, Y. 2010. Simulation and Performance Evaluation of Hydraulic Transmission Electromagnetic Energy-Regenerative Active Suspension. *2nd WRI Global Congress on Intelligent System*. 58-61.

[10] Zuo, L. and Zhang, P. S. 2013, Energy Harvesting, Ride Comfort and Road Handling of Regenerative Vehicle Suspension. *Journal of Vibration and Acoustics*. 135.

[11] Hedlund, J. D. 2010. Hydraulic *Regenerative Vehicle Suspension*. Master of Science in Mechanical Engineering thesis, University of Minnesota, USA.

[12] Khosnoud, F., Sundar, D. B., Badi, N.M., Chen, Y.K. and Calay, R.K. 2009. Energy Harvesting from Suspension System Using Regenerative Force Actuators. I*nternational Journal*. 1.

[13] Li, Z., Zuo, L., Kuang, J. and Luhrs, G. 2011. Energy-Harvesting Shock Absorber with a Mechanical Motion Rectifier. *Smart Materials and Structures Journal*.

[14] Li, P. and Zuo, L. 2014. Electromagnetic Regenerative Suspension System for Ground Vehicles. *IEEE. International Conference on Systems, Man and Cybernetics.* San Diego, CA, USA. ISBN: 9781479938407.

[15] Patil, R.U. and Gawade, S.S. 2012. Design and Static Magnetic Analysis of Electromagnetic Regenerative Shock Absorber. International *Journal of Advanced Engineering Technology*. III(II): 54-59.

[16] Longxin, Z. and Xiaogang, Z. 2010, Structure and Performance Analysis of Regenerative Electromagnetic Shock Absorber. *Journal of Networks*. 5(12): 1467-1474.

[17] Pei, S.Z. 2010. *Design of Electromagnetic Shock Absorbers for Energy Harvesting from Vehicle Suspensions*. Masters of Science in Mechanical Engineering thesis, Stony Brook University, New York, USA.

[18] Li, Z., Zuo, L., Luhrs, G., Lin, L. and Qin, Y. 2013. Electromagnetic Energy-Harvesting Shock Absorbers: Design, Modeling and Road Tests. IEEE. *Transactions on Vehicular Technology*. 62(3)

[19] Amar, N. H., Ramli, R., Isa, H.M., Mahadi, W.N.L. and Abidin, M.A.Z. 2012. A Review of Energy Regeneration Capabilities in Controllable Suspension for Passengers Car. *Energy Education Science and Technology part A: Energy Science and Research*. 30(1): 148-158.

[20] Raz, O. D. 2003. *Design and Performance of Electric Shock Absorber*. Master of Science in Electrical Engineering thesis. Louisiana State University and Agricultural and Mechanical College, USA.

[21] Abdullah, M. A., Yusof, A. A., Abd. Salam, M.F., Phuman Singh, A. S. and Mat Yamin, A. K. 2013. *Measurements & Instrumentation, Teaching and Learning Series*. Faculty of Mechanical Engineering, Module 6, Penerbit Universiti, Universiti Teknikal Malaysia Melaka.