Energy regenerative suspension test for EEV and hybrid vehicle

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Abstract. The world is demanding on the alternative fuel and reducing the fuel consumption of land transportation especially in the automotive industries. This paper emphasizes the development of the energy regenerative suspension system (EReSS) for energy efficient vehicle (EEV) or hybrid. The EReSS product is fabricated and tested on the laboratory and real vehicle. The test is conducted to test the function of the EReSS system on real vehicle. The test is done using the multimeter to record the reading of voltage produces by the EReSS system that is attached to the vehicle suspension system. The experiment starts by setting the parameters in the EReSS system which is the number of windings with a standard magnet. Road irregularity is one of the important parts of the experiment which is set to be various types of road condition and driving style. A domestic car model is selected for the EReSS test that the system can be installed. The test of the EReSS gives out the maximum output voltage of 5.6 V with 530 windings. Improvement on the material can increase the output voltage. The EReSS is function on the real vehicle by producing voltage by harvesting the kinetic energy from the suspension vibration.

1. Introduction
There are bumpy roads, the acceleration or reduction of the driving speed and the operations of the steering wheel when driving a land vehicle. This can cause the relative shock between the sprung mass and the unsprung mass. The shock is a part of mechanical power that can be recycled and reduced the energy consumption that can achieves the energy saving vehicle demands [1]. The purpose of suspension system is to isolate the road irregularity and absorbs vibration from the road to the vehicle body by using damper and spring element. The element must be designed properly and develop because of the limitation on the classic type of suspension system [2].

Regeneration of waste energy is one of the important elements in mechanical engineering fields. The mechanical element is always plays as an important role on designing a new system in mechanical. A suspension system on land vehicle is one of them which dissipate energy to facilitate passenger isolation by using viscous dampers. The analysis of energy regenerative suspension must be done properly by selecting a suitable suspension model because the model will predict the power stored by the damper [3]. The energy regenerative suspension system is already been researched by several automotive industries since the 1990s and several papers have been presented and proposed
The regenerative suspension system functions by reciprocating part of the system. When the vehicle travels on rough road, it will operate the regenerative system and harvest the kinetic energy from the suspension vibration and convert to electricity [5]. The displacement between the coil windings and magnet causes magnetic induction cutting and produces current [6].

There are many studies and researched on the regenerative suspension system and improvement done to the proposed model 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 [7]. The energy regenerative suspension system is introduced to reduce the energy consumption without losing damping efficiency and electric energy is generated during a high speed motion of the suspension system. It is function with the help of the vibrating system using single-degree-of-freedom (SDOF) system. The suspension system has high dissipation energy that is suitable for harvested for the regeneration system [8].

Electromagnetic suspension system are one of the system that attracts many researchers to replace the current passive, semi-active and hydraulic suspension system because the improvement in efficiencies and reducing the costs of production. The regeneration system ability to harvest energy is limited compared to the hydraulic system [9]. The regeneration system limitation can be prevented by a suitable selection of design, materials and geometrical optimization that will result in high force density. The electromagnetic suspension system is easier to apply because hybrid or electric car have their own energy storage system that can control the peak power and regenerative power of the system [10]. The voltage produces by energy regenerative suspension system is about 8 V for a single system and power available is about 100 W to 400 W [11, 12].

2. Methodology
The design of the energy regenerative suspension (EReSS) is selected. The design is selected by analysis of several concepts that have been proposed. The selected design is the best concept that can give out the highest voltage reading theoretically. Other than that, the selected EReSS concept is easier to be fabricated. Figure 1 shows the selected design concept of the EReSS. The concept is using 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.

![Diagram](image)

**Figure 1. Selected design concept of the EReSS.**

After the selection of the concept, the EReSS is fabricated. The fabricated EReSS system is shown in figure 2 and figure 3. The fabrication process is done by following the design concept that has been drawn on computer-aided-drafting (CAD) software. The CAD drawing is done to ensure the product component can fit to each other and ease the process of fabrication.
Next, the EReSS product is tested on the laboratory by setting up different parameter such as the number of winding and diameter of the coil. The experiment on the laboratory is done on a test rig that moves vertically direction same as the suspension system on a vehicle. In the laboratory experiment, the frequency of the system can be set and read using DasyLab software. Figure 4 shows the EReSS is tested on the laboratory experiment.

After the test on the laboratory, the EReSS will be tested on the real vehicle. Firstly, a suitable car model is selected. The selected car must have a proper suspension system that the EReSS system can be attached. The car selected is PeroduaMyvi 1.3 SE AT. The EReSS system is then attached to the car rear suspension system as the space is suitable for the EReSS to be attached. Then, the parameter of the EReSS is set for the testing on the car. Table 1 shows the parameters of EReSS used for the experiment.
After the parameters have been set up for the EReSS system, the system is then attached to the car. The EReSS is attached to the car rear suspension system with proper set up to get the reading of voltage. Figure 5 shows the EReSS is attached to the car suspension system. From the system, a multimeter is equipped to record the voltage output of the system. The equipped multimeter is put in the car to ease for recording the reading of voltage for the system.

![Figure 5. EReSS is attached to the car suspension system.](image)

### Table 1. Parameters of EReSS for on car experiment.

| Criteria          | Description         |
|-------------------|---------------------|
| Number of windings| 530, 350, 250       |
| Magnetic flux density, [T] | 0.2             |
| Magnet type       | Isotropic Ferrite  |
| Coil diameter, [mm] | 0.29             |
| Coil material     | Copper              |

3. Results and discussion
The selected car is installed with the EReSS system and run on the road. There are many road irregularity surfaces that affect the reading of voltage for the system. The reading of voltage is observed during the experiment process when the car is starts to be driven.

Figure 6 shows the result for EReSS testing for 530 windings, figure 7 for 350 windings and figure 8 for 250 windings. The maximum reading of the EReSS is get when the car is passing through a road bumper. This is because the vertical movement of the car is higher when passing through the road bumper. Frequency is one of the other reasons that cause the voltage reading is high. A higher frequency will affect the reading of the EReSS system. As on the experiment that already done on the laboratory, the higher the frequency the higher the voltage produces by the EReSS system. All the reading cannot be recorded as the frequency cannot be set to a constant. The frequency also cannot be recorded as there is no equipment for the frequency reading. This experiment is done to test the function of EReSS when attached to a real vehicle and recording the voltage produces by the system.

Other than that, the reading of the voltage is high when taking a corner with a high speed. A slalom type of driving will also give out higher voltage reading compared to normal driving style. When the car is on braking process, the voltage is also given out a higher voltage as the suspension system vertical movement is greater that straight driving. During a constant driving on a straight road, the voltage reading is slightly lower but in a constant charge. This charge of voltage can be stored for alternative power for the car electronics system such as the lighting and electronics. The use of this
voltage charge can reduce the demands on the alternator and in the same time will reduce the fuel consumption of the car as the work load for the engine is also reduced.

![Graph of Voltage against Time](image)

**Figure 6.** EReSS testing with 530 windings.

![Graph of Voltage against Time](image)

**Figure 7.** EReSS testing with 350 windings.

![Graph of Voltage against Time](image)

**Figure 8.** EReSS testing with 250 windings.
The highest voltage reading is recorded during the experiment. The maximum reading of voltage during experiment is |-5.6| V with 530 windings. Figure 9 shows the recorded maximum voltage reading.

![Image of voltage meter reading -5.6 V](image)

**Figure 9.** Maximum voltage reading of EReSS during experiment on car.

The number of windings in the EReSS system is also plays a role on the test. The higher the number of windings, the higher the voltage produces by the EReSS system as shown in table 2. The EReSS system also can be improved by using different type of magnet and coil material. The higher the magnetic flux density of the magnet, the voltage charge for the system will be higher. This is proved by the theoretical calculation for the system. This current system is only using standard type of magnet and copper coil so the voltage produced is limited. The diameter of the coil is also important for the system as the smaller the diameter of the coil the greater the voltage will be produced. Test is done on the laboratory experimentation and the result is shown in table 3. Moreover, the smaller the coil diameter, the number of windings can be added.

| Number of windings | Voltage, [V] |
|--------------------|--------------|
| 530                | 5.60         |
| 350                | 1.26         |
| 250                | 1.17         |

**Table 2.** Maximum voltage reading of different number of windings on car testing.

| Coil diameter, [mm] | Voltage, [V] |
|---------------------|--------------|
| 0.29                | 6.30         |
| 0.40                | 0.90         |
| 0.8                 | 0.78         |

**Table 3.** Maximum voltage reading of different coil diameter on laboratory testing.

4. **Conclusion**

In this research, the EReSS system that has been designed and fabricated is tested on a real vehicle and proved that the system is function on the real vehicle. The driving style of the vehicle correlates to the voltage produced by the EReSS system installed on the car. From the test, it is found that the
maximum voltage reading for standard parameters set for the experiment is 5.6 V. Other than that, the voltage output can be improved by improving the material of the electromagneticsystem of the EReSS. Equipment should be installed for the reading of frequency of the car so that all the different data of the voltage can be recorded with different value of frequency. The voltage output of the EReSS is affected by different number of windings and diameter of the coil. The road conditions are also affecting the voltage output of the EReSS system. As the voltage is produced during on car experimentation, the EReSS is proved to be function when installed on a real vehicle by harvesting kinetic energy from the vehicle suspension system.

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