



## DESIGN OF ENERGY REGENERATIVE SUSPENSION TEST RIG

Mohd Azman Abdullah<sup>1</sup>, Jazli Firdaus Jamil<sup>2</sup> and Razlan Razali<sup>2</sup>

<sup>1</sup>Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Melaka, Malaysia

<sup>2</sup>Department of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia

E-Mail: [mohdazman@utem.edu.my](mailto:mohdazman@utem.edu.my)

### ABSTRACT

Today's world is full of modern technologies and automotive industry is one of the industry that is evolving to modern technology. Hybrid and electric car is under improvement for a better efficiency. This paper emphasizes the development and analysis of retrofit electromagnetic energy regenerative suspension system test rig. The test rig will be used for the testing of the system in the laboratory. The system functions as the harvesting system that generates power for vehicle usage. Complete design of the test rig is clearly discussed in the paper including the drafting, analysis and fabrication. It is get that the designed test rig can be used for the testing which has been assembled with the main component of the real vehicle suspension system with the regenerative system. The test rig can be useful for validating the real vehicle test with the laboratory test.

**Keywords:** regenerative suspension, hybrid, test rig.

### INTRODUCTION

Energy harvesting technology is one of the promising technologies that can be develop and used in the future vehicle. One of the energy harvesting technology is the energy regenerative suspension system. The suspension system of a vehicle consists of a spring, damper and linkage that connect the sprung and un-sprung mass of the vehicle (Zhang *et al.*, 2013). Mechanical control of vibrations is one of the active areas that has been researched several years in the past with wide range of applications. External power source is needed for the technology to be applied. Regenerative harvesting system is one of the technologies that interest the researcher around the world (Sabzehgar and Moallem, 2011). The most recent research interests are on the energy regenerative from vehicle suspension system that has been presented in several papers. This is due to the automotive industry that develops the hybrid and electric vehicle for future usage (Sabzehgar and Moallem, 2012).

Primarily, the suspension system of a vehicle is used to isolate the vibration from the road from going inside the car cabin. The damper of the suspension produces heat and this energy comes from the vibration absorbed from the road (Patil and Gawade, 2012). Passive shock absorber is commonly used on vehicle which functions by using the principle of fluid frictional effects (Abdullah *et al.*, 2015a & 2015b). It is in fact that the suspension is designed for. The suspension produces vertical energy that comes from the road irregularities (Hedlund, 2010 & Abdullah *et al.*, 2015c & 2015d). The suspension consists of spring and damper to maintain the vehicle contact to the ground (Abdullah *et al.*, 2015a). There are several types of suspension system on vehicle which is passive, semi-active and active system (Abdullah *et al.*, 2015a). Each type of the suspension system has their own advantages and disadvantages (Ebrahimi, 2011). The high dissipating energy from the suspension is wasted and it is believe that the energy can be harvested and use for other purpose. The vehicle speed and suspension stiffness are another variables that is related to the dissipation energy (Bart *et al.*, 2011).

The energy lost on the vehicle suspension system is one of important energy that can be reused other than wasted (Abdullah *et al.*, 2015c & 2015d). The automotive manufacturers spend a lot of money to improve the fuel economy of vehicle as the fuel is not a renewable source. Other than that, the vehicle designers has research more on the vehicle wind drag to improve the fuel consumption of the vehicle with a streamlined body shape and using a lighter material (Patil and Gawade, 2012).

### ENERGY REGENERATIVE SUSPENSION

#### Introduction of energy regenerative suspension

The energy regenerative suspension system is already researched since 1990s and several papers has been presented. There are many researcher introduced their model of energy regenerative suspension system with different type of configuration. Tests have been done for various type of configuration and every type of the regenerative system give out different result. Each configuration has its own advantages and disadvantages (Zhang *et al.*, 2007).

The purpose of the energy regenerative suspension system is to convert the dissipating energy on the vehicle suspension system to an useful electrical energy for the vehicle usage (Abdullah *et al.*, 2015c & 2015d). 10% to 20% of vehicle component uses fuel energy other than the internal combustion engine. There are about 200 W power that produced by the vehicle suspension dissipation energy that can be used as alternate resource of energy for electrical component of the vehicle. This is proved that the vertical energy can be harvested that is useful for hybrid and electric vehicle (Pei, 2010). Energy harvesting of of vehicle is tated can be as high as 7500 W for a vehicle that has the weight of 2500 lb with a speed of 45 mph driven on the highway (Abouelnour and Hammad, 2003). Another research stated that average harvested energy is about 100 W by using the GM impact running on the highway with 16 m/s that saved about 5% driving power (Goldner, Zerigian and Hull, 2001).



There are several types of energy regenerative suspension system presented in the past few years. The first regenerative suspension system is patented in 2005 by Golber and Zerigian. They patented the magnetic shock absorber (Williams *et al.*, 2013). The other type is patented and presented by several researchers after several years. The other configuration of the energy regenerative suspension system are hydraulic, electromagnetic, electromechanical, piezoelectric and others.

### Types of energy regenerative suspension system

Piezoelectric energy regenerative suspension system has been introduced by a researcher several years ago. The piezoelectric has the ability to produce electric depending on the mechanical behavior such as vibration energy. In the paper, the researcher introduced a buzzer that has a multilayer stack of actuators to produce power. The result of the test of the piezoelectric system is that the average power generated is about 1.33 mV. The multilayer stack uses smart material with different thickness. The thickness is one of the variables that effects the power generated by the system. The higher the thickness of the multilayer stack can produce more power. In the mean time, the piezoelectric has highest reading on its working frequency which is 100 Hz and above. Meanwhile, land vehicle working frequency is lower than 10 Hz. The cost is also high for piezoelectric application (Jamaludin, 2011). The other types of energy regenerative suspension system are the application of hydraulic. The power generation on the suspension can be harvested by using the hydraulic system. A model is proposed for the system which the linear motion of the vehicle is transform into rotational motion by using a twin acting hydraulic cylinder and a motor. The converted motion functions as the driver of the electrical generator and converting the kinetic energy to electrical energy. Test is done to the proposed system and the results are really high as expected. Further improvement need to be done for the system to be more efficient with higher power generation (Hedlund, 2010).

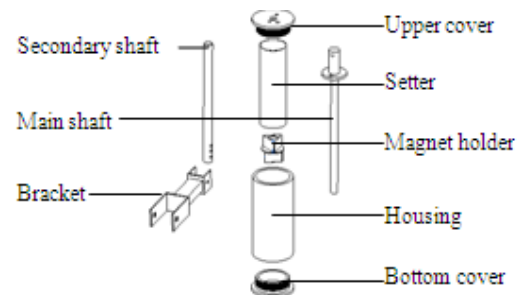
Electromagnetic energy regenerative suspension system is one of the other types. The method of the electromagnetic system is that the system is using the Faraday's Law of magnetic induction. This system is currently popular among researcher. This is because of the low cost of the prototyping and for production. The system is simple that consists of magnet and copper coil to generate power from the vehicle suspension system (Zhang *et al.*, 2013). The power generation of the electromagnetic system is depends on the magnetic flux density in the air gap. The system is designed by applying the shock absorber of a vehicle combining with the magnetic induction principle. The system can generate more power and efficient energy harvesting (Longxin and Xiaogang, 2012).

A further research has been done and presented where the hydraulic system is combined with the electromagnetic system. In the presented paper, the researcher stated that the system can harvest the energy from the vertical vibration of the vehicle suspension system. There are several factors that effects the performance of the system which are the road excitation frequency, load

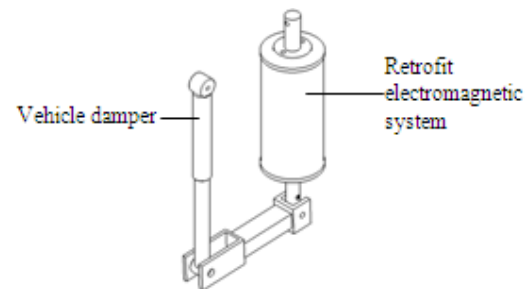
resistance and damping ratio. An experiment has been conducted for the system and get that the energy regeneration will increases and when the load resistance increased, the power generation will decreases. The optimal load resistance is robust when the excitation frequency is different. Other than that, the regeneration of the system is more sensitive to the excitation frequency other than the damping ratio. The result is that the ideal excitation frequency is depending on the wheel resonant frequency (Zhigang *et al.*, 2013).

### Design of retrofit electromagnetic energy regenerative suspension system

In the current studies, a retrofit electromagnetic energy regenerative suspension system was designed and fabricated (Abdullah *et al.*, 2015c & 2015d). Figure 1 illustrates the exploded view of the designed system where as Figure-2 shows the system when assembled with the current vehicle suspension system which is the damper.



**Figure-1.** Exploded view of the retrofit electromagnetic suspension system.



**Figure-2.** Assembly of the retrofit electromagnetic suspension system with vehicle damper.

The concept of the retrofit electromagnetic regenerative suspension system is that the system does not disturb the current suspension system on the vehicle. This will reduce the cost on developing a new damper for the present vehicle in the market. The design of the system was depending on the space of the current vehicle suspension system where the bigger the space will allowed a bigger system with higher power generation. This current system was designed based on a choosen vehicle suspension system and can be plug and play on the vehicle. The design is currently using the computer-aided-drafting (CAD) software. The CAD software helped on the fabrication



process with detail dimensions (Abdullah *et al.*, 2014a, 2013a, 2013c). The dimension of the design was taken from one of the vehicle that available in the market. After the design was completed, the system was then fabricated as shown in Figure-3. The fabrication process was based on the CAD drawing to get the exact dimension for the system to avoid any error (Abdullah *et al.*, 2014b, 2013b & 2013d) when applied to the vehicle suspension system.



**Figure-3.** Fabricated retrofit energy regenerative suspension system.

The fabricated retrofit system used different materials for each of the component such the shaft was using the steel and body is teflon. This is to prevent the magnet from stuck to a mild steel material and cannot move freely by following the movement of the suspension system of the vehicle. The main component of the system was the copper coil and magnet. These two components were the core of the system where it will harvest the kinetic energy and convert it to electrical energy. The principle is simple where reciprocating of the suspension will energize the system and the magnet with the copper coils will cut the magnetic induction lines and generates electricity to be stored for the vehicle usage. In addition, this system does not need any other power resource to operate and save more on the vehicle fuel energy. The higher magnetic flux will produce more power such as using the permanent magnet that is already available in the market. The advantages of this system is supporting more power for vehicle usage without depending on any other system power source and the current vehicle suspension will be keep in original condition.

## DESIGN OF TEST RIG

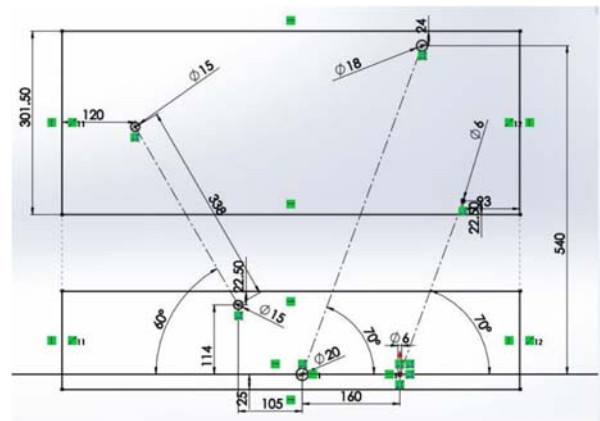
### Introduction to test rig

Test rig is equipment that is used for testing the performance of mechanical product or project. A test rig is always been used for testing the damping for vehicle suspension system. The retrofit electromagnetic suspension system need a test to measure the performance of the system (Abdullah *et al.*, 2015c & 2015d). So, a test rig was needed for the system to prove the functions of the system. The test setup must be carefully design to avoid error when the data

is taken. The current test rig in the laboratory was for testing the damper in the suspension system but for the system it will be directly measure by the shaking of the machine. This will give different result between the testing done on the real vehicle where the spring and the damper system were not included in the test. A test rig that consists of both spring and damper were designed to get a better reading by taken in the effect of the vehicle suspension system component as well as the retrofit electromagnetic regenerative suspension system.

### Dimensioning process

The design of the test rig was developed by measuring a real vehicle suspension system configuration of Perodua Myvi. The dimension and the location of both spring and damper were measured in actual vehicle to get real vehicle suspension condition. This test rig used a choosen vehicle damper and spring system applied with the retrofit regenerative suspension system. So, in the laboratory test rig, additional rig that consists spring and damper was fabricated. The other purpose is to validate the laboratory testing with the real vehicle testing data. The first step of the design was to get the actual configuration of the choosen vehicle. Figure-4 shows the suspension configuration dimension of the choosen car.



**Figure-4.** Suspension configuration dimension of the choosen vehicle.

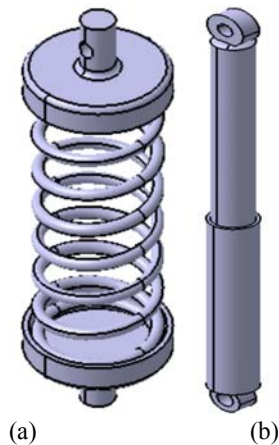
The dimension of the suspension configuration was taken by diassembling the real vehicle suspension system. The dimension was taken by using the vernier caliper and ruler for the main components which are the spring and damper position. The angle of the components was also measured to get actual configuration. Figure-5 shows the actual position of the regenerative suspension on the vehicle suspension system.



**Figure-5.** Actual vehicle suspension configuration.

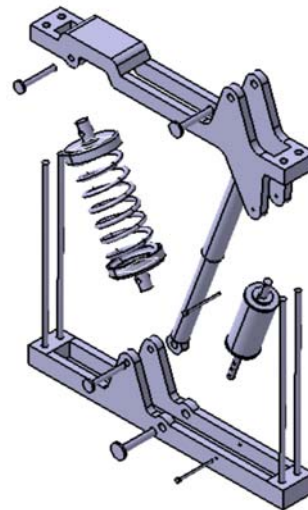
### Test rig design process

The main component for the suspension system was then drawn on the CAD software to be assembled with the designed test rig. This was to ensure that the test rig was fit with the suspension system with the retrofit system. Figure-6 illustrates the damper and spring drawing on CAD software.



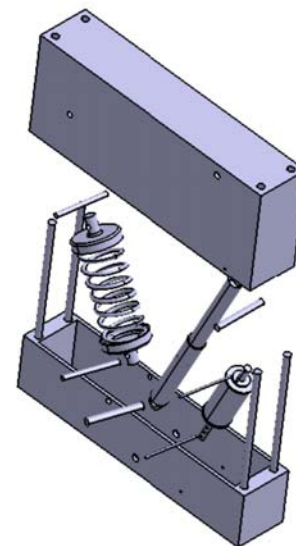
**Figure-6.** Vehicle suspension system (a) spring and (b) damper.

After completing the three main components for the test rig, two designs of the test rig were drawn on the CAD software. The design of the test rig is following the dimension that had been taken on the real vehicle. Figure-7 shows the first design and Figure-8 shows the second design of the test rig.



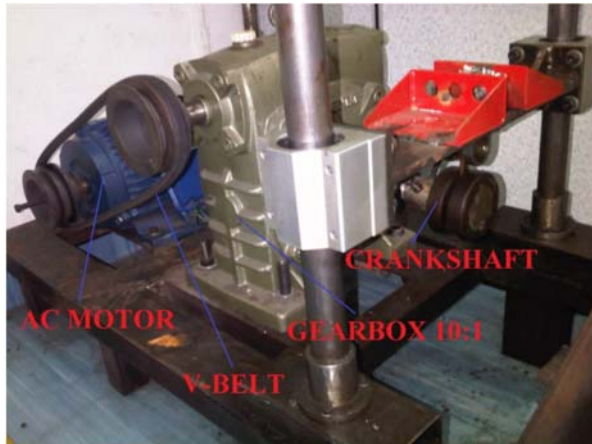
**Figure-7.** First test rig design.

The first test rig design was complex with several processes to be done. Other than that, the system was low in safety precaution which there was no cover for the component. The safety measure is important when doing experiment and the first thing to be considered in engineering is safety. When the screw was loosen, the component can be disassembled and cause accident to the experimenter. By considering the safety measures for the experiment, the second design of the test rig was done with safety measures. The safety equipment was that the upper part of the test rig was covered with a plate to avoid accident when the component was disassembled in the main test rig. The design of the test rig was an additional test rig that will be used on the main test rig in the laboratory to applied the usage of the spring and damper of a vehicle. The main test rig with the components is shown in Figure-9.



**Figure-8.** Second test rig design.



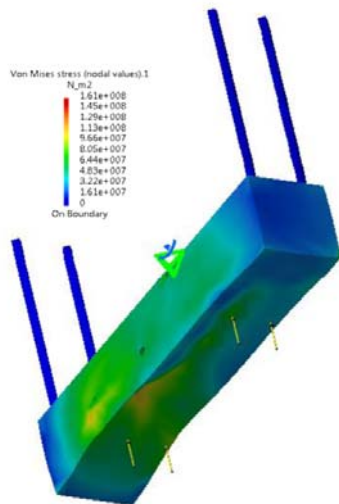


**Figure-9.** Main test rig with components.

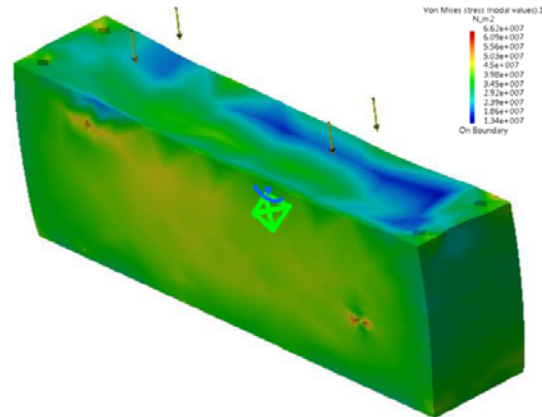
In addition, the second design will reduce the time to be fabricated compared to the first design which has several complex shapes. The other advantages of the second design were that the test rig needed less material to be fabricated and thus save the fabrication cost. The most important thing for the test rig was that it can be used for the testing with safety measures.

#### Stress analysis

After the designing process was finished, the stress analysis is performed for the second design which is chosen for fabrication. The analysis was done to predict the physical behavior when suppressing loading (Abdullah *et al.*, 2014a, 2014b & 2013a). The material used for the test rig was mild steel where it can stand more load compared to other material. Furthermore, mild steel material is cheap to reduce the cost of fabrication (Abdullah *et al.*, 2013a, 2013b & 2013c). Figure 10 shows the lower part of the test rig deformation and Figure-11 shows the upper part of the test rig deformation.



**Figure-10.** Lower part of the test rig stress distribution.



**Figure-11.** Upper part of the test rig stress distribution.

The force applied was 783.96 N to both lower and upper part of the test rig components. This is equal to about 7690 kilograms load that applied to the test rig. The displacement for the lower part is 0.00126 mm and 0.0007 mm for the upper part of the test rig. Both deformation displacements are small and the design is safe to be use and fabricate. Other than that, the test rig can be applied almost 8000 kilograms load without being damaged. Welding process is also needed for joining of the test rig. The complete fabrication of the test rig is shown in Figure 12. The safety factor for this design is more than 2.5.

#### Fabrication process

The final steps were fabrication of the test rig that had been designed and analyzed. As mentioned, the material used for the fabrication was mild steel with the thickness of 3 mm. There were several processes needed to complete the fabrication. The machines that used for the fabrication were cutting machine, shearing machine and bending machine (Abdullah *et al.*, 2014a, 2014b, 2013a, 2013b & 2013d).



**Figure-12.** Complete fabrication of the test rig.

The component such as the spring, damper and retrofit electromagnetic energy regenerative system are



assembled with the complete fabricated test rig. It shows that the configuration can be fit with all the main component for the testing. The movement of the test rig is also tested and successfully functioned as expected.

## CONCLUSIONS

In this paper, the test rig module for the laboratory testing of retrofit electromagnetic energy regenerative suspension system was fabricated based on the real vehicle suspension configuration and dimension. Based on the discussion and analysis, the test rig can be used on the main test rig on the laboratory without fail. Besides, the test rig was user friendly and easy to install. All the main components with the safety measures that has been considered during the laboratory test. Furthermore, the test rig module can be useful on proving and validating the retrofit electromagnetic energy regenerative suspension system that will be test on the real vehicle driving in the future.

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