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DESIGN SELECTION AND ANALYSIS OF ENERGY REGENERATIVE SUSPENSION

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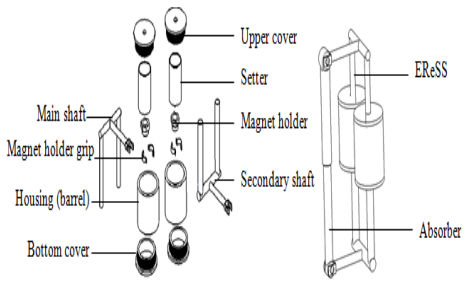
Graphical abstract



Abstract

Nowadays, world demand for alternative fuels has led to an advanced research and development of hybrid and electrical vehicles. This paper presents the design development and analysis of energy regenerative suspension (EReSS) system to harvest wasted energy from vibration of a vehicle. The source of the wasted energy is the kinetic energy produced by the vibrating structures of the vehicle. Electromagnetic method was used to harvest the wasted energy. Several design concepts of the EReSS are discussed and proposed in this paper. Three-dimenstional (3D) modeling of the EReSS was performed using the Computer-Aided-Drafting (CAD). Design analysis was performed in order to find the best conceptual design of the EReSS, which then it will be fabricated. From the design analysis, the EReSS is attached as retrofit, outside the suspension system, and it will not disrupt the current suspension system. By the help of a moving suspension system, it helps vehicles to move smoothly on irregular road surface conditions.

Keywords: Regenerative suspension, hybrid, electric vehicle, CAD.

1.0 INTRODUCTION

Suspension is a system that consists of a spring, damper and linkage, which connect the sprung and un-sprung mass of a vehicle and allow the vehicle and the wheel to move independently from each other [1]. The damper is designed to dissipate vibration energy into heat and to absorb the vibration produced from the irregular road surface. The green technology manufacturing is important for the future of automotive industries because a suspension system has an important source of energy dissipation and the energy is wasted. The wasted energy can be harvested and convert to regenerative energy to improve the vehicle fuel efficiency. Other than that, the harvested energy can be converted to electricity and stored for hybrid vehicle usage. The stored electricity can be used as the power of the vehicle electronics [2]. Manufacturers of vehicle industry have made costly development to improve the fuel economy and car designer also struggled on reducing wind drag to reduce the fuel consumption of a vehicle. The regenerative shock absorber can reduce the fuel consumption as the harvested energy can charge the battery of the vehicle and help to power up the battery instead of using the alternator on the vehicle [3].

There are several ways to convert kinetic energy from vibrating structures to form a more usable energy. One method is using the hydraulic and electro-chemical regenerative suspension. The research on the system has been done with a designed shock absorber [4]. The most efficient method is the electromagnetic regenerative

suspension system. The harvested energy from the vibration is enough to complete the requirement in the consumption process for the system [5]. The recent research has discussed the use of electromagnetic suspension to absorb vibration in the vehicle suspension system is an acceptable alternative to harvest the wasted energy from the vertical vibration on the vehicle suspension system. The system is suitable for converting the kinetic energy to electricity to use on the electric vehicle and stored for vehicle electronics and high in performance [6][7]. There are several more researches focused on the system. The system functions by the displacement of the body and wheel that cause relative displacement between the magnet and coil windings. The reciprocating of the suspension will operate the regenerative suspension and the coil will cut the magnetic induction lines and produces current in the coil.

2.0 METHODOLOGY

The conceptual design of energy regenerative suspension (EReSS) is firstly sketch manually. There are several concepts sketched to be selected as the best concept. After that, the concept is sketched using the Computer-Aided-Drafting (CAD) software. The CAD software used is CATIA V5 R20. The CAD software is used to ease the fabrication process of the EReSS. The CAD software illustrates the drawing for each of the concepts. The dimensions of the CAD drawing will simplify the design, fabrication and fix to the shock absorber when attached. The designs of the EReSS take place by the part which the magnet and the coil are located on the system. The materials in the EReSS are coil and magnet. There is a different type of magnet and coil sells in the market. These two materials are the main component that is important to the EReSS.

Fig. 1 illustrates the first concept of EReSS. The design concept was a simple squared-shape. The joining was welded on the lower part of the housing. The inner part of the system can be changed by opening the upper cover. The material used for this concept was steel in order to prevent it from rusting since the system will be located under the vehicle body and exposed to the surrounding air.

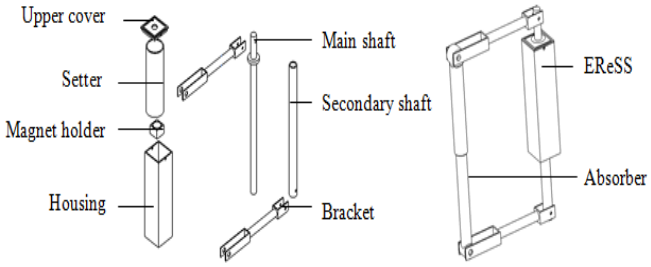


Figure 1 The first conceptual design of the EReSS

Fig. 2 illustrates the second concept of the EReSS system which is similar to shaft and bushing. The housing can be separated from the top cover and bottom cover. This concept eases the setting of the parameter in the system. The coil and magnet can be changed by disassembling parts of the system. This design used aluminum material which is light weight. Furthermore, the aluminum is anti-corrosion material that is suitable to be used under the body of a vehicle. The aluminum helps to minimize the overall weight. Fig. 3 illustrates the third concept of EReSS system for the vehicle. This third concept used the concept of double barrel, which is doubling the system. This concept uses the same material of the second concept which is aluminum. As the system is double, the weight will be double but the size will be smaller for each barrel. The size of the system depends on the vehicle suspension space. The design is suitable for a certain vehicle model. Other than that, the cost of the fabrication will be high.

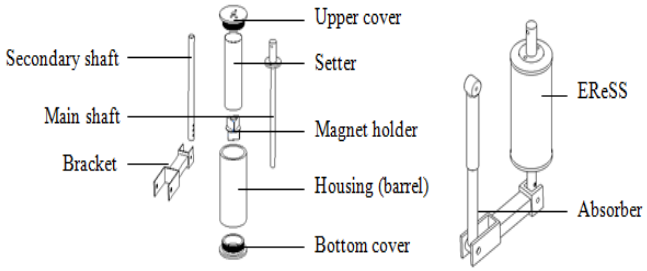


Figure 2 The second conceptual design of EReSS

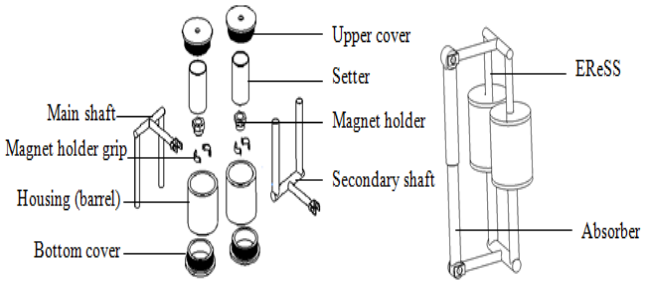


Figure 3 The third conceptual design of the EReSS

The number of windings that used on the coil can be calculated using Eq. 1

$$N = \frac{L}{Dc} \quad \text{(Eq. 1)}$$

Where N is the number of windings, L is the length of the wire used, (m) and Dc is the diameter of the coil, (m). The length of the wire used can be determined using the formula. The theoretical value of voltage produce by the EReSS can be calculated using Eq. 2.

$$Ve = \pi \cdot N \cdot Dr \cdot Vz \cdot Br \quad \text{(Eq. 2)}$$

Where Ve is the voltage produce in volt, (V), N is the number of windings, Dr is the average diameter of the windings, (m), Vz is the lateral velocity of the magnet, (m/s) and Br is the magnetic flux density, (T). The lateral magnet velocity, Vz can be calculated using the Eq. 3.

$$Vz = \frac{V \cdot h}{\sqrt{h^2 + w^2}} \quad \text{(Eq. 3)}$$

The parameters of EReSS are shown in Table 1 and the theoretical value using Eq. 1, Eq. 2 and Eq.3 of each design is shown in Table 2. In Table 2, the material used for each design is stated with the estimated cost of fabrication for the system.

From the theoretical value, material and estimated cost, the designs are analyzed by using the weighted rating matrix (Table 3) for obtaining the best conceptual design. The criterias on the matrix are stated by referring each of the design concept and the theoretical value [8]. The best conceptual design was then selected to be fabricated. The fabrication process will follow as previous design for manufacturing approach [9][10]. The design was chosen by taking the highest value in the total rating. The weight rating value was set from 0 to 4, which represents the unsatisfactory and very good respectively.

Table 1 Parameters assumption for the system

Speed, [km/h]	20
Magnetic flux density, [T]	0.2
Coil diameter, [mm]	0.29
Speed bump, [mm]	h = 75, w =300

Table 2 Theoretical value, material and estimate cost for the system

Type/Criteria	Design 1	Design 2	Design 3
No of winding	380	530	500
Length of wire, [m]	58	80	64
Voltage, [V]	0.93	1.30	1.22
Material	Steel	Aluminum	Aluminum
Estimate cost, [RM]	250	400	550

From the theoretical value, material and estimation cost, the design is analyze by using the weighted rating matrix as illustrates in Table 3 to get the best concept design. The criteria on the matrix are stated by referring each of the design concept and the theoretical value. The best concept design is then chosen to be fabricated. The design is chosen by taking the highest value in the total rating. The weight rating value is set from 0 to 4 which stand from unsatisfactory to a very good rating.

Table 3 Weighted decision rating matrix.

Criteria	Importance weight	Concept Alternatives					
		1		2		3	
		Rating	Weighted rating	Rating	Weighted rating	Rating	Weighted rating
Low cost	0.10	3	0.30	2	0.20	1	0.10
Low maintenance	0.05	3	0.15	3	0.15	2	0.10
Easy to use	0.05	3	0.15	4	0.20	3	0.15
Light weight	0.05	2	0.10	4	0.20	3	0.15
Safe to use	0.10	3	0.30	4	0.40	4	0.40
High performance	0.15	3	0.45	4	0.60	4	0.60
High efficiency	0.15	3	0.45	4	0.60	4	0.60
Adjustability	0.05	2	0.10	3	0.15	3	0.15
Reliability	0.10	2	0.20	4	0.40	3	0.30
Durability	0.10	3	0.30	3	0.30	3	0.30
Robustness	0.10	3	0.30	3	0.30	3	0.30
Total	1.00	NA	2.80	NA	3.50	NA	3.15

3.0 RESULTS AND DISCUSSION

From this study, the best conceptual design selected for the EReSS system was the second design. The concept has the highest rating compared to other conceptual designs. The EReSS was proven to be functional in harvesting energy from the vibration of suspension. This design fulfill the criteria that is important such that high in performance. The chosen design will be fabricated and tested in order to verify the theoretical value calculated for the design. This type of EReSS can only be used on a vehicle suspension system as there is high dissipation energy on the system. Additionally, the system was designed base on a retrofit approach where beneficially, it can be installed on or removed from conventional suspension system without major modification on the spring and damper.

4.0 CONCLUSION

In this research, the design of Energy Regenerative Suspension (EReSS) was performed in order to choose the best conceptual design to be fabricated. The concept is targeted to be well-functioned when it is attached to a vehicle shock absorber. This system is beneficial for lowering fuel consumption and increasing vehicle efficiency. In the near future, it is expected that the EReSS can also generate an alternative energy by harvesting the kinetic energy from the vibration of vehicle. This later on can be used to recharge a battery of hybrid or full electric cars.

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