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DESIGN OF ELECTROMAGNETIC REGENERATIVE SHOCK ABSORBER AS A TOOL OF HARVESTING VIBRATION ENERGY ON VEHICLE

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ABSTRACT: This paper discusses vibration energy on the vehicles shock absorber which was converted to electrical energy by using magnet and coil. Principally, vibration energy on the shock absorber will be wasted into friction and heat form. But, in this study are able to obtain the vibration energy and utilize it as a new energy source for the vehicle by adding the mechanism of harvesting energy electromagnetic type. Linear movement of the shock absorber is captured by electromagnetic generator mechanisms which consist of a coil and a permanent magnet. The produced output of the electromagnetic generator can be used as new energy source for the vehicle. The mechanism of harvesting energy used electromagnetic generator was chosen through literature study that has been done by the researcher. Furthermore, the electromagnetic generator obtained the smallest of energy loss. The experimental measurement used galvanometer, the results were obtained that the resurrection energy was 2.5 mV on 1.5 Hz, 4.24 mV on 2.0 Hz, and 5.6 mV on 2.5 Hz on excitation frequency.

Keywords: Shock absorber, Harvesting energy, Electromagnetic generative, Vibration energy, Excitation

1. INTRODUCTION

Based on the data which was obtained on Center for Energy, Transportation and the Environment (CETE), it is known that vehicles will work effectively using 16% of fuel energy from the result of combustion used. The rest 62% will be engine losses in heat and vibration form, 11% engine idling, 6% transmission losses, and 2% from the adding of an accessory such as Air Conditioner (AC), wiper, etc. The shock absorber is a component which is used as the pedestal of vehicle's body and to isolate the vehicle from the vibration cause of the road's contour [8, 9].

The changes of mechanism energy happened on the conventional shock absorber (up and down the energy of vehicle's body) into heat energy which was happened because of the movement of fluid on the shock absorber. Meanwhile, the design changes happened on the electromagnetic regenerative shock absorber which was the up and down energy on the shock absorber captured and changed it into excitation energy to actuate the electromagnetic mechanism which is set on the Shock absorber. So, the loss energy on the shock absorber can be reused. This regenerative shock absorber is expected to be able to keep down the loses energy value in the heat and vibration sector which is 62% of the efficiency value of vehicle increase.

2. LITERATURE REVIEW

There are several studies relate to a Regenerative shock absorber which was used as the background of this article. One of them is Li Chuan, et al [1] with regenerative shock absorber by using hydraulic rectifier as rectification flow and then go through the hydraulic motor.

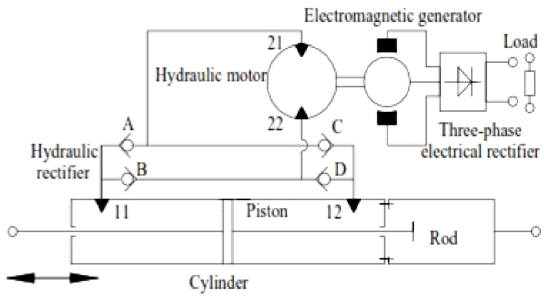

Fig.1 Regenerative shock absorber with a hydraulic motor

Compression and rebound movement of the shock absorber is rectified through a rectifier and then goes to the hydraulic motor. The function of the hydraulic motor is to spin the generator. The source of motor movement on the generator is obtained from the pressure fluid which was come from the rectifier.

The generator spin produces electrical energy which is used as a new energy source. Furthermore, a shock absorber liquid damper type [2]. From the test, it was obtained that the damping energy is a nonlinear curve. This is the damping energy's value of the test as shown in Fig. 2.

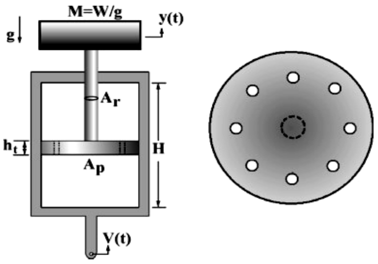

Fig.2 Liquid damper shock absorber

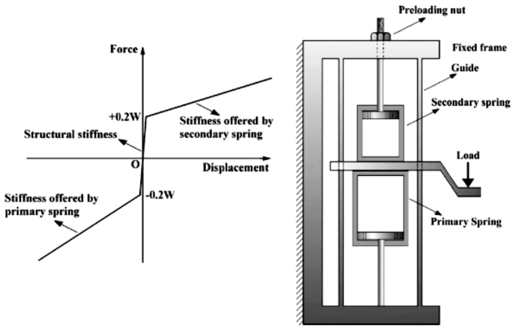

Fig.3 Force dumper curve of liquid dumper shock absorber

Last, HEMSA (Hydraulic Electro Mechanic Shock absorber) from Institut Teknologi Sepuluh Nopember [3]. The following picture is the design of HEMSA from Institut Teknologi Sepuluh Nopember.

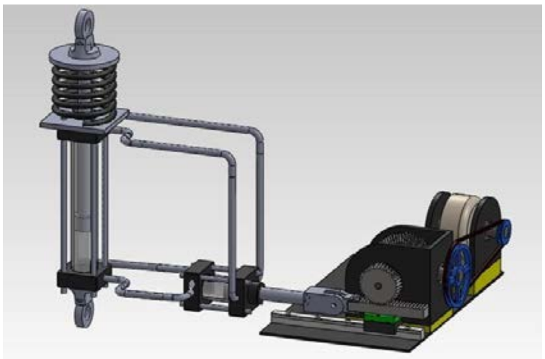

Fig.4 Hydraulic Electro Mechanic Shock absorber (HEMSA) from ITS

From the test with the load 85 Ω, 125 Ω, 250 Ω, it was obtained the resurrection energy on 1.7 Hz excitation frequency in sequence based on the load, are 0,52 watt, 0,39 watt, 0,32 watt. With the cylinder variation 40:40, double port pipe and 85 Ω, 125 Ω, 250 Ω load, it was obtained velocity sprung mass value in sequence based on the load, are 2.270 m/s^2, 2.084 m/s^2, 1.744 m/s^2.

Based on those literature sources, the writer was interested to make a regenerative shock absorber with the electromagnetic mechanism. Besides the simple construction design, this electromagnetic system also has small loss energy.

3. BASIC THEORY

The basic theory in this study was developed based on the concept of vibration that produces electricity. Furthermore, any bumpy system experiences damping up to a certain degree so that energy is anticipated by friction and other prisoners. Then, harmonic vibration, logarithmic decrement, the effect of vehicle's velocity toward human, Loretz law was described in this paper.

3.1 Harmonic Vibration

Usually, vibration not only occurs on the spring system nor the prop, the base of the system will also experience the vibration in harmonic vibration form.

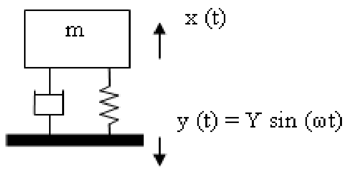

Fig.5 Free Body Diagram excitation on the base

From the free body diagram on picture 5 and excitation on the base on picture 6, the equation of movement that was obtained is:

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0 \quad (1)$$

The Steady-state response of the mass is xp(t) which is can be formed into this following equation:

$$x_p(t) = \frac{kY\sin(\omega_t - \theta_1)}{\left[(k - m\omega^2)^2 + (c\omega)^2\right]^{1/2}} + \frac{(\omega c Y \sin(\omega_t - \theta_1))}{\left[(k - m\omega^2)^2 + (c\omega)^2\right]^{1/2}} \quad (2)$$

So, the system equation above can be written as:

$$x_p(t) = X\sin(\omega_t - \theta_1 - \alpha) = \left[\frac{k^2 + (c\omega)^2}{k - m\omega^2 + (c\omega)^2}\right]^{1/2} \sin(\omega_t - \theta_1 - \alpha) \quad (3)$$

Where the value of $\theta_1 = tan^{-1}\left(\frac{C\omega}{k - m\omega^2}\right)$

That equation can be simplified into:

$$x_p(t) = X\sin(\omega_t - \theta) \quad (4)$$

Where $\frac{\boldsymbol{X}}{\boldsymbol{Y}}$ is displacement transmissibility:

$$\frac{X}{Y}=\left[\frac{k^2+(c\omega)^2}{\left(k-m\omega^2\right)^2+(c\omega)^2}\right]^{1/2} \tag{5}$$
$$=\left[\frac{1+(2\xi r)^2}{(1-r^2)^2+(2\xi r)^2}\right]^{1/2}$$

And,

$$\theta=\tan^{-1}\left[\frac{mc\omega^3}{(k-m\omega^2)^2+(c\omega)^2}\right] \tag{6}$$
$$=\tan^{-1}\left[\frac{2\xi r^3}{1+(4\xi^2-1)r^2}\right]$$

The relevance of damping ratio, frequency ratio, and displacement transmissibility is shown in the following graphic:

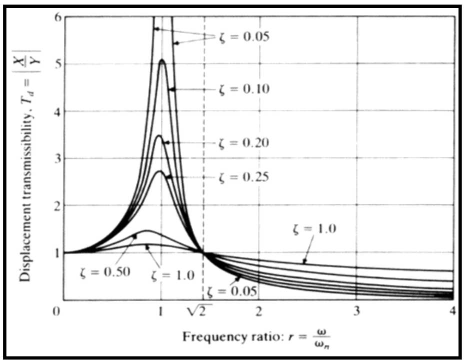

Fig.6 Displacement transmissibility vs frequency ratio

3.2 Logarithmic Decrement

Logarithmic decrement is a display of amplitude reduction on free damp vibration. The value of damping constantan on the system will be known if the logarithmic decrement (δ) is also known.

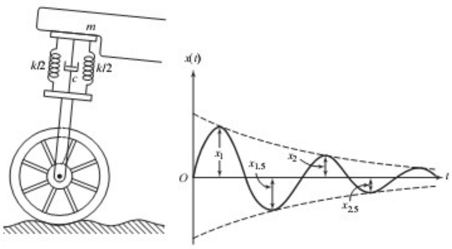

Fig.7 Displacement transmissibility vs frequency ratio

From the picture above, t is known as time on the first and second peak, x1danx2 show the peak movement, and form the ratio:

$$\frac{x_1}{x_2}=\frac{e^2\pi\varsigma}{\sqrt{1-\varsigma^2}} \tag{7}$$

If both parts of logarithm were naturalized, it will be:

$$\delta=\ln\frac{x_1}{x_2}=\frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \tag{8}$$

The equation above can be written as:

$$\boldsymbol{\zeta}=\frac{\boldsymbol{\delta}}{\sqrt{(\mathbf{2}\,\boldsymbol{\pi})^{\mathbf{2}}+\boldsymbol{\delta}^{\mathbf{2}}}} \tag{9}$$

From displacement graphic, the function of time will be obtained from x1 and x2, and then the value will be included into decrement equation, so the equation will be:

$$\boldsymbol{\zeta}=\frac{\boldsymbol{\delta}}{\sqrt{\mathbf{4}\,(\boldsymbol{\pi})^{\mathbf{2}}+\boldsymbol{\delta}^{\mathbf{2}}}} \tag{10}$$

Where: ζ = damping ratio
δ = logarithmic decreament = $\ln\frac{x_1}{x_2}$

The value of damping ratio can be found by using this formula:

$$\boldsymbol{\zeta}=\frac{\boldsymbol{C}}{\boldsymbol{C_c}}=\frac{\boldsymbol{C}}{\mathbf{2}\sqrt{\boldsymbol{km}}} \tag{11}$$

Where: k = Spring contant (N/m)
C = Damping constant damping
m = Load mass (kg)

3.3 The Effect of Vehicle's Velocity Toward Human

The main movements that was experienced by the driver and passenger during the ride are velocity or deceleration and vibration. Endurance information about human body toward the velocity is very important as references on the endurance of vehicle's body design toward the impact.

The pleasure criteria based on velocity number according to ISO 2631 standard, will be shown in this following graphic:

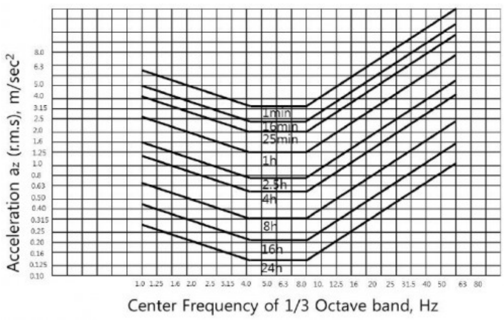

Fig.8 The pleasure criteria graphic based on ISO 2631 standard

3.4 Loretz Law

The permanent magnet array of the regenerative electromagnetic shock absorber is connected to wheel axles of the vehicle and the coil windings array is connected to the framework or body of the vehicle [10]. When the vehicle travels on rough roads, the relative displacement between framework or body and wheel axles causes relative displacement between coil windings array and permanent magnet array. At this point coil groups will be cutting the magnetic induction lines in the air-gap, thus current occurs in the coil and in the mean time damping force occurs correspondingly. The direction of the damping force is relatively opposite to the movement of the coil group. When the conductor moves perpendicularly to the direction of magnetic induction line, the Lorentz force can be defined as:

$$F = q \cdot V \cdot B \qquad (12)$$

Where: F = Lorentz force (N)
q = queantity df electricity (C)
V = Velocity of electric charge (m/s)
B = Magnetic flux density (T)

4. DESIGN AND PARAMETER

4.1 Coil

The coil is used as a track movement of the permanent magnet. This coil will capture GGL from the result of magnet movement in it. This is the design of coil RSA.

Fig.9 Coil use for track movement

4.2 Permanent Magnet

This magnet is used as a moving component which is installed in the rod shock absorber. The rod movement which was installed the permanent magnet on the coil will cause the electricity force. This is the construction of permanent magnet on the rod shock absorber.

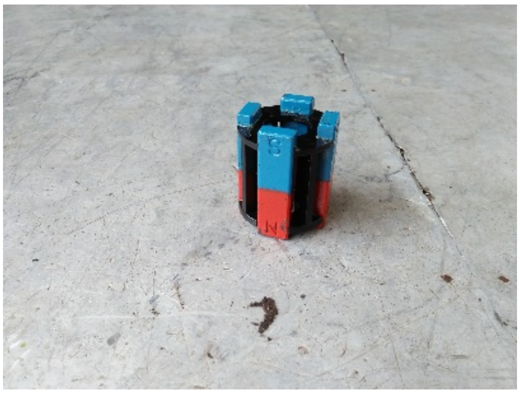

Fig.10 Permanent magnet

4.3 Full Design Concept

On this part, it is shown that the mechanism of harvesting energy attachment on the up and down rod movement which pass the coil.

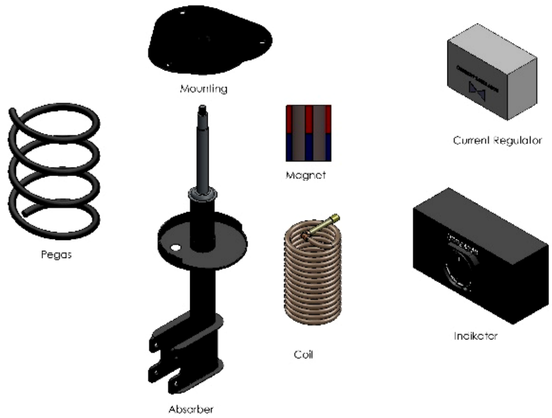

Fig.11 Component detail RSA

When it assembly and ready to test:

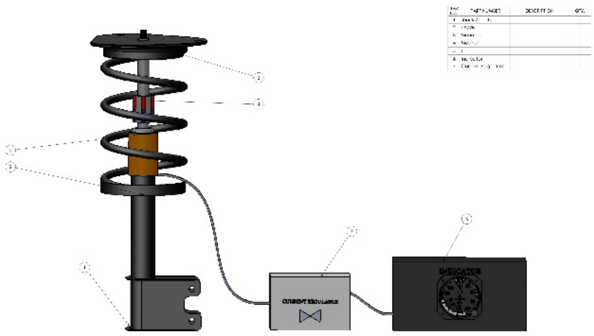

Fig.12 RSA assembly ready to test

4.4 Research Methodology

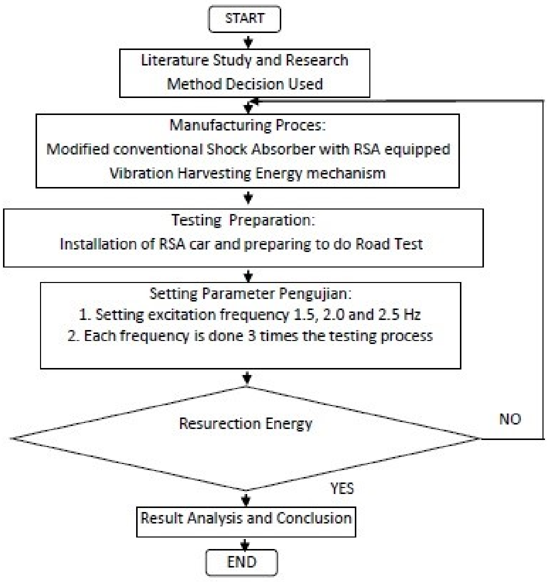

Fig.13 Research Methodology

Fig.14 Shock absorber with harvesting energy mechanism

Fig.15 Installing the regenerative shock absorber in the car

Research methodology in this paper was described as shown in Fig 13. Before the RSA manufacturing process, the design mechanism of harvesting energy system installed in the shock absorber was performed as shown in Fig 11. After the concept of shock absorber design is obtained, then the next step is to choose the material. In this study, the permanent magnet with ferrite magnet is selected. This material has a permanent magnet that can function as a rotor that travels through the coil. A permanent magnet mounted on the rod shock absorber so that it can move translations due to the excitation force of the vehicle movement to generate electric current.

A coil as the main component serves as a capture motion up and down magnet with rod shock absorber, resulting in a potential difference between the two ends of the wire that has the potential to produces electric current. In this study, the wire used to construct a coil is a copper wire with a diameter of 0.7 mm with a total length of 5 m wire. After two main components as a prototype of the mechanism of harvesting energy (permanent magnet and coil) is performed, the next step is the installation of energy harvesting mechanism in rod shock absorber. The permanent magnet is in the rod position while the coil is in the cylinder hydraulic shock absorber as shown in Fig 14.

5. TEST RESULT AND DISCUSSIONS

Experimental phase in this study is installing the regenerative shock absorber in the car (Fig. 15) and then road test. From the road test by using bump 50 mm high to replace the road surface, the resurrection energy that was obtained on RSA as shown in Table 1.

Table 1 Energy resources from the experiment

No	Frequency	Energy Resources			
		Test I	Test II	Test III	Average
1	1.5 Hz	2.3	2.6	2.5	2.5 mV
2	2.0 Hz	4.30	4.37	4.1	4.24 mV
3	2.5 Hz	5.4	5.8	5.6	5.6 mV

From the test obtained different values on each test, where the highest electrical energy generated at a speed of 40 km/h that is equal to 114.33 mV. At a higher speed of 60 km/h there is a decrease in electrical energy produced, of which only 79 mV. This condition is a phenomenon of excitation frequency obtained by vehicles away from the value of 1 so that the number of frequencies received by the vehicle is less than the excitation frequency. Table 1 explains the electrical energy generated by regenerative shock absorber is very small. This condition is due to the limited movement of magnetic translations across the windings. Where this condition affects the different potential energy generated on both ends of the wire. Therefore, to get greater energy generation, there are 3 aspects that must be optimized as the number of winding turns, permanent magnet dimension and magnetic displacement in traversing in the coil

6. CONCLUSION

Harvesting energy mechanism (RSA) that has been installed on the Shock absorber, tested by road test method. Furthermore, the shock absorber is placed on the vehicle and then read the electrical energy it produces. Vehicles conditioned through bump artificial form of 5 pieces of blocks with a height of 3cm each and have a distance of each 5cm. Tests were conducted on three variations of speed: 20 km/h, 40 km/h and 60 km/h. The test results are shown by Galvanometer where the current obtained is 43.67 mV at a speed of 20 km/h, 114.33 mV at a speed of 40 km/h and 79 mV at a speed of 60 km/h. The resurrection energy from RSA is relatively small. It was caused by the limitation of the step length of the “stroke” area from the permanent magnet on passing the coil area. To wider the length of its step, we need to do a redesign and choose better material in order to get bigger resurrection energy. Besides, the design optimization is focused on the number turns, wire diameters, permanent magnet dimension and stroke are of the coils.

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