Design and built of a regenerative shock absorber

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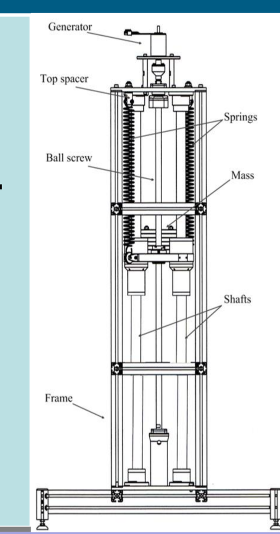
1. Introduction

Conventional damping systems are made using hydraulic shock absorbers can be found on cars, trains, motorbikes and other transportation systems. Over the years, efforts to make better use of fuel have made transportation more efficient, but it is estimated that 2% to 5% of fuel is still wasted on suspension. This project adds to the wide range of research that have been carried out in recent years by producing a prototype that can be maximise the harvestable energy from a vehicle suspension. The motivation behind the manufacturing of a prototype is to demonstrate that a small improvement on a car's efficiency can result in high savings for consumers and end users. Following this idea, a compact electromechanical energy harvester has been developed, which is mainly a lead screw based inerter coupled to a mechanical motion rectifier and a generator.



2. Previous Work

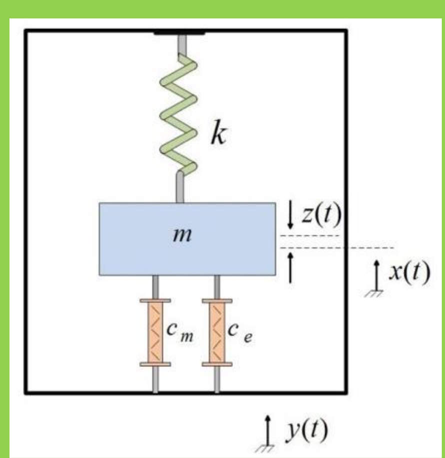


Figure 1: Schematic diagram of linear harvester

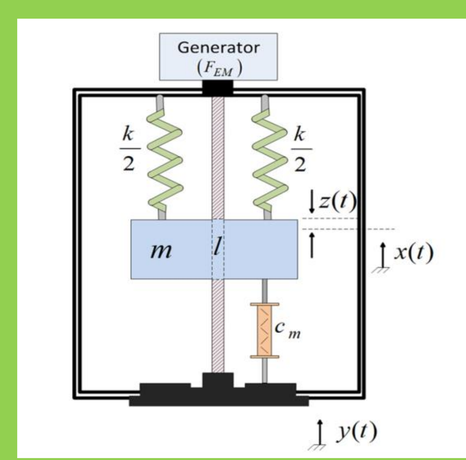


Figure 2: Schematic diagram of rotational harvester

$$m\ddot{z} + (c_e + c_m)\dot{z} + kz = -m\ddot{y}$$

$$\left(m + j\left(\frac{2\pi}{l}\right)^2\right)\ddot{x} + c_m\left(\frac{2\pi}{l}\right)^2\dot{x} + kx(t) = j\left(\frac{2\pi}{l}\right)^2\ddot{y} + c_m\left(\frac{2\pi}{l}\right)^2\dot{y} + ky(t) + F_{EM}$$

The goal of an energy harvesting device is to generate electrical power, its parameters with respect to the defined constraints should be selected in order to maximize the output power.

$$P_{l-ave} = \frac{1}{2}\frac{R_l}{(R_l+R_i)^2}{K_t}^2\omega^2{Y_0}^2 \times \left(\frac{(m\omega^2)^2}{(k-(m\omega^2)^2 + ((c_m + \frac{{K_t}^2}{R_l+R_i})\omega)^2}\right)$$

$$P_{b-average} = \frac{1}{2}\frac{R_l}{(R_l+R_i)^2}{K_t}^2\left(\frac{2\pi}{l}\right)^2\omega^2Y^2 \times \left(\frac{(m\omega^2)^2}{(k-(m+j\left(\frac{2\pi}{l}\right)^2)\omega^2)^2 + ((c_m + \frac{{K_t}^2}{R_l+R_i})(\frac{2\pi}{l})^2\omega)^2}\right)$$

Λ_{em} is a non-dimensional electromechanical coupling coefficient of an energy harvesting system. The efficiency of the harvesting system can be defined as:

$$E_{l,P_{max}} = \frac{\Lambda_{em}}{4+2\Lambda_{em}} \quad \text{where:} \quad \Lambda_{em,l} = \frac{K_t^2}{C_m R_i}$$

$$E_{b,P_{max}} = \frac{\Lambda_{em}(\sqrt{1+\Lambda_{em}})}{(1+\sqrt{1+\Lambda_{em}})^2 + \Lambda_{em}(1+\sqrt{1+\Lambda_{em}})} \quad \text{Where: } \Lambda_{em,b} = \frac{T_i^2}{C_{bg}R_i}$$

In real conditions such as the marine environment, the device may vibrate over a broadband of frequencies and random in nature. The expected output power under broadband excitation can be defined as:

$$E(p) = \frac{\pi s_0 m^2 R_l {T_i}^2}{(c_{bg}(R_l+R_i)^2 + {T_i}^2(R_l+R_i))(m + j\left(\frac{2\pi}{l}\right)^2)}$$

When the system is subjected to band-limited white noise if $S_{Y_A}(\omega) = S_0, \omega_1 \le |\omega| \le \omega_2$, for which the corresponding power spectral density of the load current is:

$$S_1(\omega) = \begin{cases} -\dfrac{m^2(\frac{2\pi}{l})^2{T_i}^2\omega^2 R_l S_0}{(k-M\omega^2)^2(R_l+R_i)^2 + c^2\omega^2(R_l+R_i)^2}, & \omega_1 \le |\omega| \le \omega_2 \\ 0, & Elsewhere \end{cases}$$

However, for broadband white noise, $[\Delta(\infty,\xi) - \Delta(0,\xi)]$ tends to unity, the term acts as correction factor applied to a band-limited vibration system.

$$E[P(t)]_{\omega_1 \le |\omega| \le \omega_2} = \frac{m^2(\frac{2\pi}{l})^2{T_i}^2\omega^2 R_l S_0}{M(R_l+R_i)^2 c} \times \left[\Delta\left(\frac{\omega_2}{\omega_n},\xi\right) - \Delta\left(\frac{\omega_1}{\omega_n},\xi\right)\right]$$

3. Experimental Results

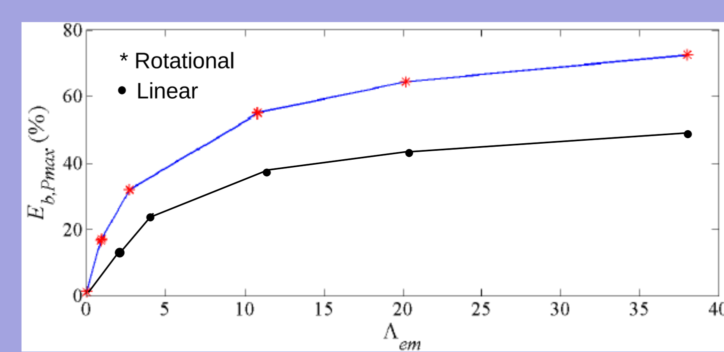


Figure 3: Efficiency of rotational/Linear electromagnetic energy harvester versus Λ_{em}

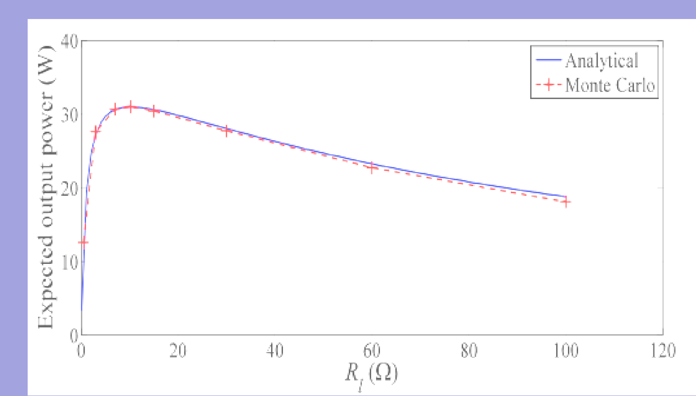


Figure 4: Expected power under broadband random vibration

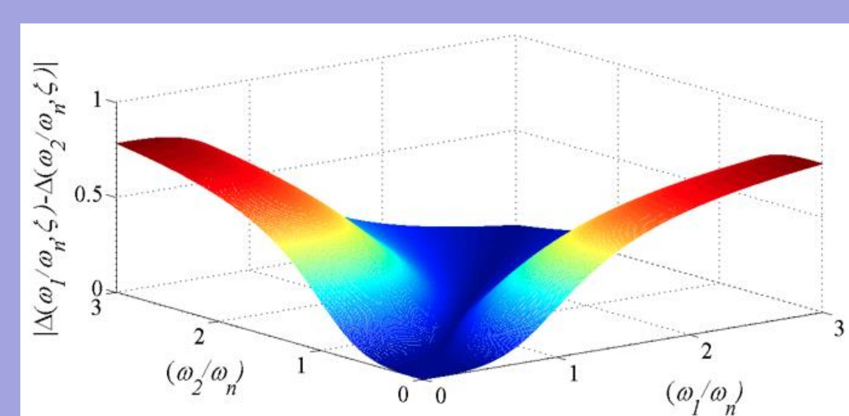


Figure 5: Correction factor for calculation of the expected output power of energy harvester under band-limited excitation for a device with $\xi = 0.5$

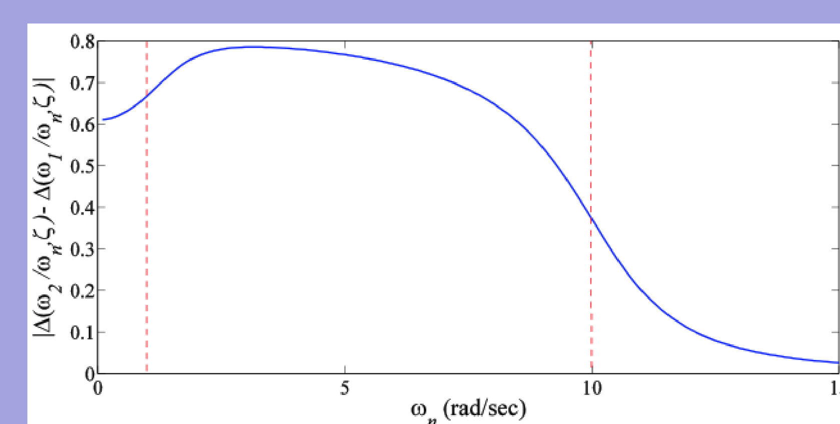


Figure 6: Correction of the expected output power of the simulated energy under band-limited excitation ($\omega_1 = 1\ rad/s$ and $\omega_2 = 10\ rad/s$) harvester versus ω_n

4. Concluding Remarks

- For a linear system, the maximum efficiency is always less 50%.
- In the case of a rotational system, the harvester can be designed so as to have an efficiency greater than 50%. The criterion that guarantees the efficiency of a rotational system is more than 50% is derived.
- Increasing the size of energy harvesting system can lead to increased efficiency of both constrained linear and rotational systems.
- The expression of output power of rotational system under broadband excitation is obtained. It is seen that the output power is independent from the natural frequency of system. Also, the harvest more power the moment of inertia of device shall be minimized.
- When the system is under a band-limited excitation, the output power is a function of the natural frequency. The optimum natural frequency is within the band sides. The process to determine the optimum natural frequency of rotational system in this condition is introduced.

5.Current Work

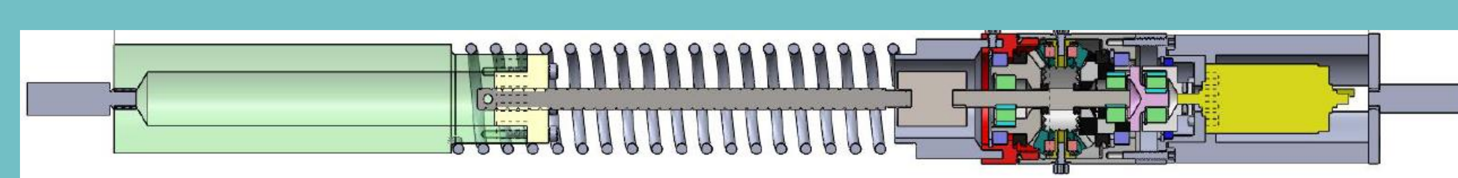


Figure 7: Final design of lead-screw shock absorber

Figure 8: Manufactured parts assembled

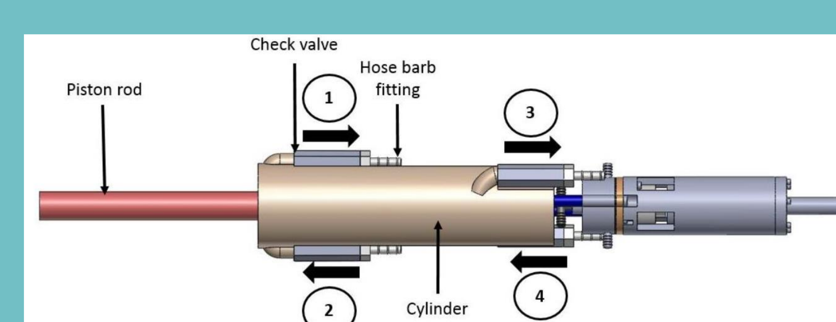


Figure 9: Hydraulic Damper Overview

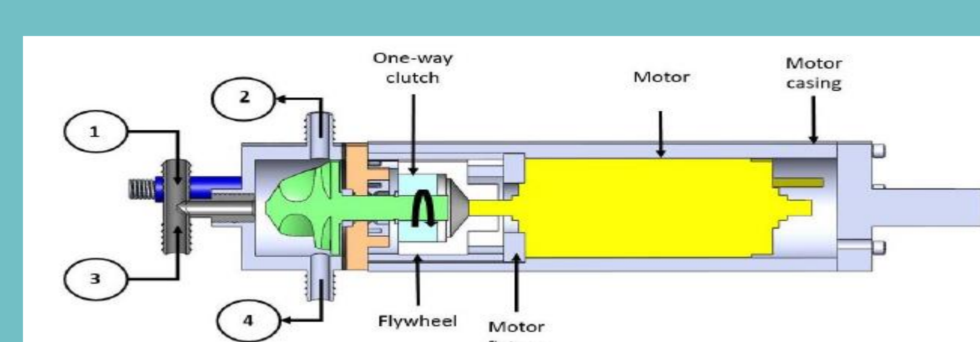


Figure 10: Cross section of Hydraulic Shock Absorber

A prototype of lead-screw shock absorber, including a motion rectifier and a generator has been developed. Experiments can now be carried out to characterise its performance. It can also be tested with/without the motion rectifier in order to verify the output signal with the case when electronic signal rectification is used. Hydraulic shock absorbers will also be developed and their performances will be compared with conventional dampers.

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