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Research paper



Parametric Study for Vibration Energy Harvester System

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Abstract

This paper presented a concept of single degree of freedom (SDOF) electromagnetic vibration energy harvester system with a new technique which introduced two moving mechanical system in a device. New techniques applied in proposed energy harvester system enable to operate at wide bandwidth frequency range, and with two resonances frequency by control the parameter factors. The development of device based on the parameters factor through mathematical modelling. The simulations result based on on the parametric factor shown the proposed mechanical concept in energy harvester system enable to increase bandwidth frequency and vibration transmissibility.

Keywords: *Parameter factors, mathematical modelling, vibration energy harvester system*

1. Introduction

Scavenging energy from mechanical vibration become the most study for harvesting research area due to its high availability in technical environments (Twiefel and Westermann 2013). Vibration has garnered the most interest because of their abundance, high theatrically achievable conversion efficiency and vibration transmissibility through different media (Beeby, Tudor, and White 2006)(Harne and Wang 2013). In addition, vibrational energy is abundant sources which energy is obtained resulting from a human and machine motion (Mitcheson et al. 2008), rotary motion (Khameneifar, Moallem, and Arzanpour 2011), water and wind flow(Li and Lipson 2010).

The main mechanisms in energy harvester system are mechanical system and transducer system. Both systems are related each other, so the efficiency of generator or energy harvester system depend on it.

Mechanical mechanism is system more on physical design which involved the motional design(Cheng, Cepnik, and David P.Arnold 2015) and a transducer is device that converts mechanical motion into electrical energy (Spreemann and Manoli 2012). The overall performance of harvester system is dependent on the design and techniques applied in the mechanical system of harvester. The mechanical system is the heart of the harvester that provides the changing magnetic field needed for current to be induced in the coil. In this research, the design of mechanical system of harvester has developed based on a few factors such as parameters factor and linear behavior.

Even though a plenty of research done on the vibrational energy harvester, but it still has several problem and limitation. Bandwidth and linearity of energy harvester are common problem faced by many researchers. Narrow bandwidth implies constrained resonance frequency and limit applications. The range of frequency depends on the efficiency of the system linearity. The mechanical design for energy harvester system will influence the capability of the system to operate at wide bandwidth frequency range.

The lack in designing of electromechanical system (EMS) caused the limitation to operate at optimum condition. If energy harvester system not fully utilize vibration level from the external sources (ambient sources), it will be causing the lack in utilizes vibration level from ambient sources to energy harvester system, which known as displacement challenge. Displacement challenge is capability of energy harvester system to amplify the vibration level from external source that indirectly it will increase the performance of system. This problem is related to mechanical system mechanism.

The capability and efficiency of energy harvester system is determined based on amount of output voltage and has ability to operate in wide operating frequency range. The main problem is to generate maximum power in time-varying frequency range. Electrical output is produced by the electromagnetic transducer motion in energy harvester systems which depend on the mechanical system movement, so the lack of efficiency mechanical mechanism will affect the electrical output.

The purpose of this paper is to improve the performance of the linear harvesters based on the parametric factor involved in mechanical design in order to operate the system at time-varying frequency. New techniques and method have applied and introduced in proposed vibration energy harvester by develop the understanding of parameter factor and mathematical model for parametric factors.

2. Harvester design and modeling

2.1 Device configuration and operation

The overall performances of harvester system depend on the design and techniques applied in the mechanical system of harvester. The mechanical system is the heart of the harvester that provides the changing magnetic field needed for current to be induced in the coil. In this research, the design of mechanical system of harvester had developed based on a few factors such as parameters factor and linear behavior. Figure 1 illustrated the design of energy harvester system which had fully assembled. Apart from the mechanical system, it also consists of electromagnetic system: magnet (3) and copper coil (4). All components were involved in design has marked with numerical symbol as depicted in Figure 1 and explanation for each of components detail had stated in table 1.

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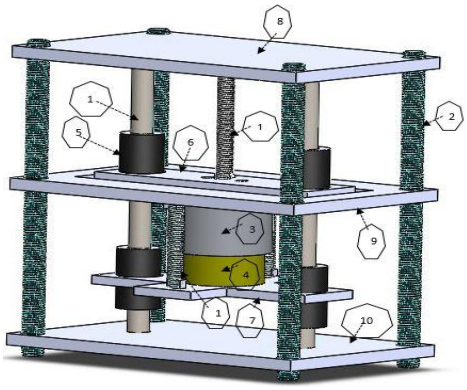


Figure 1: Prototype design for energy harvester system

Table 1: Components description of energy harvester system.

Numbers	Components.
1	Compressed spring
2	Thread road
3	Magnetic core
4	Copper coil
5	Linear bearing
6	Upper stage
7	Lower stage
8	Upper fixture
9	Middle fixture
10	Base fixture
11	Linear shaft

In the proposed energy harvester system, mechanical system was divided into two mechanical subsystems which are upper system and lower system as depicted in Figure 2. In energy harvester system, during operating only the upper and lower system will move when exposed with external vibration source. By using two moving system such as upper and lower system, this technique indirectly will increase the performance of system in term of frequency range. Frequency level for upper and lower system has been tuned and set to operate at certain frequency level. The method used to tune and set the frequency is tunable frequency tuning method. The direction of motion for upper and lower system had been study by using MATLAB software to determine the direction motion for both whether in-phase or out-phase during operating.

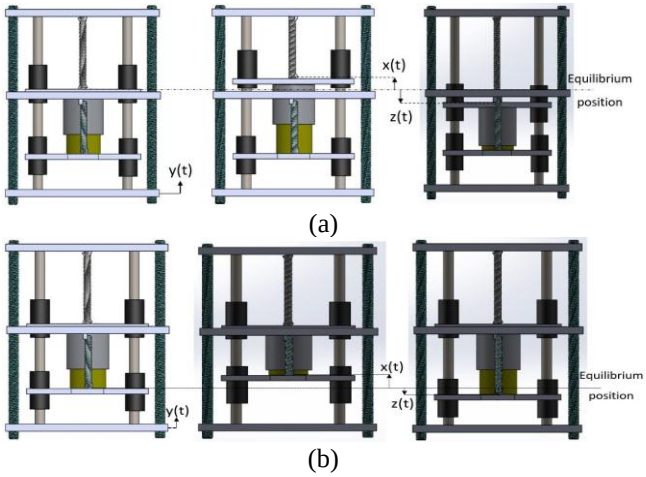
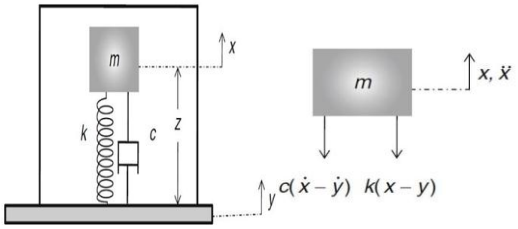


Figure 2: Illustration motion between magnet and copper coil for (a) upper stage and (b) lower stage.

2.2 Parametric factor on displacement transmissibility for harvester system.

In energy harvester system concept, the system absorbs the vibration sources from external vibration sources to operate which known as vibration transmissibility. Mathematical modelling was developed were involve relationship between parametric factor on vibration transmissibility effect. Figure 3 shows the basic illustrates of motion for single degree of freedom (SDOF) of energy harvester system during exposed on external sources where m is seismic mass (kg), k is spring stiffness (N/m), c is damping coefficient (N.s/m), y is displacement of external force, x is absolute displacement of seismic mass and z is relative deflection of the system.



(a) (b)

Figure 3: Schematic for SDOF of spring-mass-damper;(a) system connected to external sources; (b) free-body diagram at an arbitrary instant including effect of support displacement, y (t).

Based in figure 3, according to Newton's second law, the standard form of the differential equation of mass motion can be written as

$$m\ddot{x} + c\dot{x} + kx = c\dot{y} - ky \tag{1}$$

The seismic mass relative deflection to housing denoted as $z = x - y$ and equation 1 is rewritten by replace x value with z value as the dependent variable and divided by m yield which can be simplified as

$$\ddot{z} + 2\xi\omega_n\dot{z} + {\omega_n}^2 z = -\ddot{y} \tag{2}$$

Recalling that $c = 2\xi\omega_n m$. The excitation y(t) can be assuming in the harmonic form $y = A\sin\omega t$. Then Eq. 2 become

$$\ddot{z} + 2\xi\omega_n\dot{z} + {\omega_n}^2 z = \omega^2 A\sin\omega t \tag{3}$$

Where ω is forcing frequency (rad/s), ξ is damping ratio and ω_n is angular frequency of the system. Since the oscillation of the response is at the same frequency as the excitation, hence the steady state relative response can be express as

$$z(t) = A_1\sin\omega t + A_2\cos\omega t \tag{4}$$

Differential Eq.3.6 into $\dot{z}(t)$ and $\ddot{z}(t)$,then substituted into Eq.3.4 and then simplified the solution into two equations as

$$A_1 = \frac{F_0(k - m\omega^2)}{(k - m\omega^2)^2 + c\omega^2} \quad ;$$
$$A_2 = \frac{F_0 c\omega^2}{-(k - m\omega^2)^2 - c\omega^2} \tag{5}$$

Substitute A_1 and A_2 into equation $z = \sqrt{A_1 + A_2}$. At the end of equation become

$$\frac{z}{y} = \frac{r^2}{\sqrt{(1 - r^2)^2 + (2\xi r)^2}} \tag{6}$$

Denoted that $r = \frac{\omega}{\omega_n}$, is frequency ratio. Recall back where z is mass relative reflection and y is displacement of support based

According to the eq. 6, the functionality of vibrational energy harvester system depends on the transmissibility of external vibration into the system and the effectiveness of mechanical mechanisms. The level of effectiveness of mechanical mechanism in energy harvester system can be control and predict with three type of parameters which are damping coefficient, seismic mass and material stiffness.

3. Simulation results and discussion

In figure 4, shows the results of simulation for upper and lower stage motion in form of shape of sinusoidal curves with different external frequencies values sources as discussed in section 2.1. Table 2 shows parameters used for simulation.

Table 2: Parameters for mathematical simulation of upper and lower stage motion.

Parameter	value
Spring stiffness	48 N/m
Upper stage resonant frequency	22.77 rad/s
lower stage resonant frequency	52.37 rad/s
Magnetic core mass	64 g
Copper coil mass	20 g
Upper stage damping ratio	0.1
Lower stage damping ratio	0.1

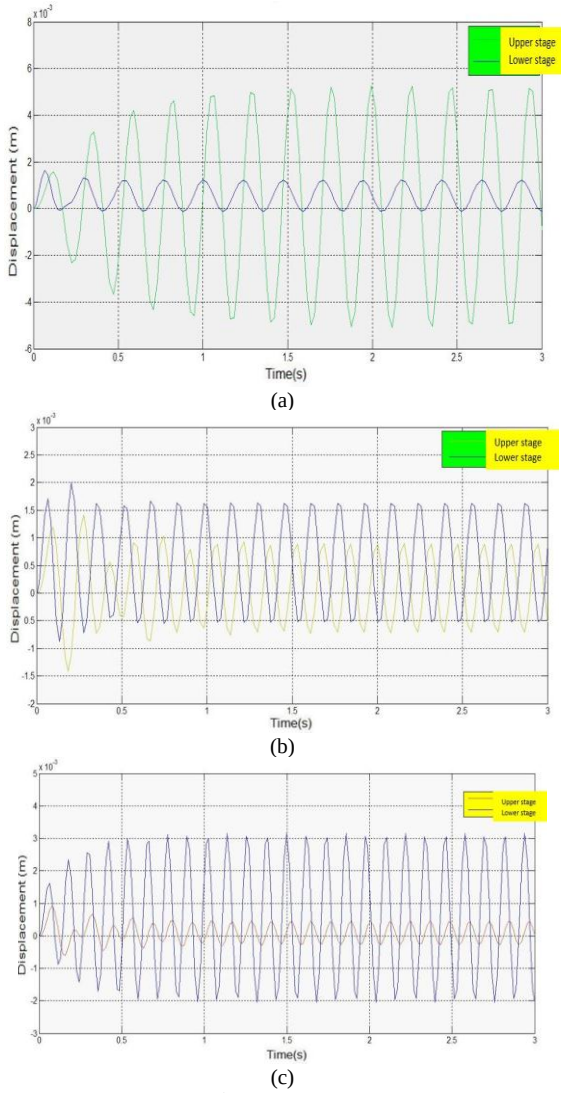


Figure 4: Simulation result for the direction motion at same excitation amplitude but difference frequency level (a) 22.77 rad/s, (b) 40 rad/s and (c) 52.37 rad/s

Based on the result in figure 4, clearly shown that the stage for both systems are not moving in same direction even at difference frequency level by refer to motion of graph curves against time. upper and lower stage represent the magnet and copper coil or know as electromagnetic system.

The upper stage had shown the higher amplitude respondent at frequency 22.77 rad/s since it is natural frequency for upper system and it same goes to lower system when at frequency level 52.37 rad/s. At frequency level 40 rad/s, the both systems shown the same result as before which does not have same direction motion, so even though at any frequencies level, both stages still show the opposite direction motion.

With these assumptions based on mathematical modelling, the proposed VEHs with two moving system enable increase the performance of VEHs to operate at wide bandwidth frequency range and at the sometime increase the efficiency output voltage of the system

In figure 5 shows the simulation result for displacement transmissibility based on the parametric factors

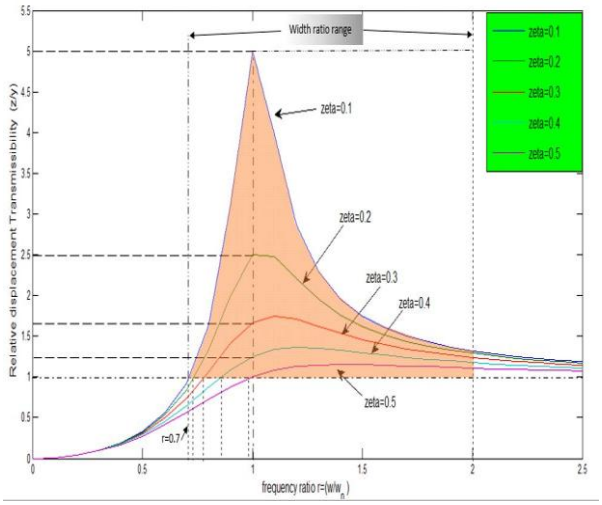


Figure 5: Graph showing the responding of displacement transmissibility at difference zeta values for relative motion.

Based on the graph in figure 5, difference value of zeta (damping ratio) influenced the amount of the vibration absorb to harvester system from external. To produce higher voltage output and ability to operate at wide bandwidth frequency, the system needs to maximize the vibration level transfer from surrounding by refer to relative motion displacement factors.

All the information in graph are identified based on the derivation of mathematical involved as discussed in section 2.2.

4. Conclusion

The simulations result shown the proposed mechanical mechanism concept based on the parametric factor for energy harvester system enable the system to operate more efficient.

The proposed mechanical mechanism design enables the system to operate at wideband frequency range. The performance of linear harvester can be control by using the parametric control method.

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