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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

OPTIMIZATION OF HYBRID MICROGENERATOR BASED ON ELECTROMAGNETIC AND PIEZOELECTRIC

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor's Degree in Electronics Engineering Technology (Industrial Electronics) with Honours

by

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours. The member of the supervisory is as follow:

………………………………
(En Mohd Fauzi Ab Rahman)

ABSTRAK

Pada masa kini, orang ramai terdedah dengan perkembangan teknologi penjana kuasa tanpa wayar yang mampu menjana sumber elektrik. Penuaian tenaga ditakrifkan sebagai kaedah mengumpul dan pada berkumpul semua tenaga dari satu atau lebih sumber tenaga dan menyimpannya untuk digunakan kemudian. Salah satu penggunaan sistem penuaian tenaga melalui penggunaan getaran tenaga sebagai kuasa sumber yang dijana . Terdapat beberapa kaedah dalam menjana penuai tenaga berdasarkan getaran yang termasuk piezoelektrik , elektromagnetik dan elektrostatik. Dalam kajian ini, penuaian tenaga hibrid akan memberi tumpuan kepada piezoelektrik dengan penjana mikro elektromagnet yang digabung bersama. Tambahan pula, tujuan projek ini secara amnya untuk menyiasat dan menganalisis penuaian tenaga hibrid termasuk menganalisis bagaimana untuk dioptimumkan sistem. Projek ini akan menganalisis kuasa output yang dijana berdasarkan penuaian tenaga hibrid untuk piezoelektrik dan elektromagnet dengan mengubah konfigurasi struktur termasuklah kedua-dua disambungkan secara siri dan selari. Model penuaian tenaga yang terdiri daripada dua penuai hibrid yang rasuk piezoelektrik dan gegelung dengan magnet bar. Oleh itu, sebagai penjana getaran akan menjalankan untuk menganalisis simulasi.

ABSTRACT

Nowadays people are exposed with the development of technology with wireless energy harvesting that capable of generating electricity. Energy harvesting is defined as the process of deriving external source energy and connecting them into useable electrical energy and then stores it for powering miniscale wireless electronic devices. There are some methods used to generate electrical energy that based on vibration such as using piezoelectric, electromagnetic and electrostatic. The hybrid energy harvester that will be focused in this project consists of piezoelectric and electromagnetic that being coupled together. The aim of this project generally is to investigate and check the performance result when these piezoelectric and electromagnetic are investigated. This project will be analyze the output power generated based on hybrid energy harvesting for piezoelectric and electromagnetic by varying the structures' configurations including connected it in series and parallel configurations. The energy harvesting models that consist of two hybrid harvester which piezoelectric cantilever beam and coil with magnets bar on the shaker as vibration generator will be carry out to analyze the simulation.

DEDICATION

This thesis is dedicated to my parents who taught me that the best kind of attitude to have is that never stop learning and they always encourage me that if it is done one step at a time, even the largest task can be accomplished.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

AC	-	Alternating Current
AWG	-	American wire gauge
DC	-	Direct Current
EM	-	Electromagnetic
F	-	Farad
MEMS	-	Micro Electromechanical Systems
A	-	Excitation Acceleration
ζ_T	-	Damping Ratio
k	-	Spring Constant
ω_n	-	Resonant Frequency
ω	-	Excitation Frequency
C_T	-	Damping Coefficient
$z(t)$	-	Net Displacement
Y	-	Amplitude of Vibrations
$\emptyset$	-	Phase Angle
τ	-	Torque

CHAPTER 1
INTRODUCTION

1.1 Background

Energy harvesting is defined as a method on gather and accumulates all energy from one or more energy sources and storing them to be used later. There's a lot today a system that use the application of energy harvesting and being optimized day by day. The commonly applied is energy harvesting on mechanical energy which through vibrations energy used. The transduction mechanism is being applied through the vibrations including piezoelectric, electromagnetic, and electrostatic techniques (Stephen Beeby, 2010).The energy generate by vibrations energy easily can be applied through anything including through human behavior like walking and running, effect on wind blowing on vibrates things and so on. The vibration is abundance and it just all around us.

Many of the vibration energy harvesters in the literature nowadays are based on single generator such as piezoelectric and electromagnetic. The hybrid energy harvesting will integrating two of these elements in one component, and harmonize them together which then would increase the generation of power output. For this project basically will focus on mechanism of piezoelectric and electromagnetic. Electromagnetic means the behavior of magnets with coil while for piezoelectric cantilever is made up piezoelectric materials that able to generate the electrical charge whenever the mechanical load or vibrations energy applied to them. This hybrid energy harvesting capable on take over the battery. As we all knew, people depends on batteries as their power source for daily lives however they sometimes facing interruption on its lifespan, cost and functions. Therefore the development of energy harvesting technique might attract people nowadays to use it. For making the system more effective, the investigation regarding the configurations of structures for these two micro generator should be designed and analyze.

1.2 Problem Statement

Commonly batteries are used to power up any systems which acted as main sources. People depends on batteries or current source as their power source for daily lives however they sometimes facing interruption on its lifespan, cost and functions Therefore, energy harvesting micro generator nowadays influenced people enough to take over used of battery as there has been an increasing on development of energy harvesting based on vibrations including by using piezoelectric and electromagnetic. Alerted that, many of the vibration energy harvesters in the literature nowadays are based on single generator such as piezoelectric, electromagnetic. Therefore, by integrating two of these elements in one component and harmonize them together would increase the generation of power output.

1.3 Objectives

The aims or objectives of this project are as follows:

(a) To investigate the hybrid energy harvesting of vibration energy using piezoelectric and electromagnetic through vibration energy generated.

(b) To design hybrid energy harvesting micro generator structure based on piezoelectric and electromagnetic mechanism.

(c) To test and evaluates the micro generator behaviour through data analysis.

1.4 Scope

This project will focus on the behavior of hybrid micro generator by using piezoelectric and electromagnetic. Optimization will take place once the performance result is investigated when connecting these two elements in series and parallel. The structure arrangement of piezoelectric and electromagnetic connections will be studied rather than when connected individually. The electrical circuit for the energy harvesting micro generator includes two rectifier and storage system with filter which by involving the behavior of capacitor. The frequency of the mechanical excitation will depend on the source that is less than 10Hz for human movements and typically over 30Hz for machinery vibrations (Roundy et al., 2003) [4]. As this project related to the shaker which classified as machinery, the range of the excitation frequency that can be tested during the analysis is over than 30Hz.

1.5 Project Significance

As the project is being carried out, there are many related party that might interested which including the researchers on investigating the hybrid energy harvesting of vibration energy using piezoelectric and electromagnetic through vibration energy generated. While the practitioners and industries might interest on designing hybrid energy harvesting micro generator structure based on piezoelectric and electromagnetic mechanism. For the testing and evaluating the micro generator behavior through data analysis, all the researchers, practitioners, industries should also be benefits as this product is preferred as an advanced system on generating output power rather than use of battery to activate any devices or even products. Therefore the product is mainly really benefits to the users or societies.

1.6 Summary

Commonly, energy from single source like piezoelectric only or electromagnetic only is not enough to achieve the power requirement, therefore to overcome the low power generated, the hybrid energy harvesting devices among the piezoelectric and electromagnetic micro generator able to solve this[5]. Combinations of piezoelectric and electromagnetic in a single unit could be generating greater power instantaneously and be stored in the capacitor for later used. By sharing piezoelectric cantilever beam with magnet attached to its free end, the size of the hybrid unit could be remained same as the single unit which a combination. This means, when vibrations generated, both micro generator operates simultaneously which explained a harmonic combination into a single unit micro generator. The smaller the unit, the better the unit is, as it can employ in the small scale electronic device for electrical powering purpose.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lately, there is showed some interest towards the development of miniaturized system and micro electromechanical systems (MEMS). Due to that development, energy harvesting is being applied as an alternative energy sources which commonly generated through vibration (Robert GHERCA, 2011). Vibrations is commonly preferred to be choose as a sources for energy harvesting as it is abundance including in motion of vehicles, movement of people and also seismic vibrations which varying in frequency and amplitude (Bin Yan, 2010). Kinetic energy is a part of vibrations which being applied through the energy sources from household goods, industrial plant and equipment, moving structures such as automobiles and airplanes, stationary structures such as buildings and bridges and other human based applications (S. P. Beeby1, 5-9 June 2005) .There are some methods to generate energy harvesting through vibration that are electrostatic which is a capacitive while piezoelectric and electromagnetic as the inductive (Robert GHERCA, 2011). This project will be investigating the method of piezoelectric and electromagnetic for energy harvesting. As the energy harvest is through vibrations and electromagnetic, the energy produced is in alternating current (AC) output. Therefore, in order to use the energy harvested into storage component like battery or to some electronic devices, it is needed to obtain a stable direct current (DC) output. For accomplish that, AC to DC converter which consists of rectifier bridge and smoothing capacitor need to be used.

2.2 Power Generator of Vibration

Dibin Zhu states in his article that in energy harvesting system, there are some possible alternative energy sources include photonic energy (Norman, 2007), thermal energy (Huesgen et al., 2008) and mechanical energy (Beeby et al., 2006) (Tan, 2011). Among all these three, mechanical energy can be applied in a condition where the photonic and thermal energy is not suitable. This means, system of energy harvesting through the mechanical energy is more advanced in approaching for power up the electronic systems. The photonic and thermal energy performance is affected by the surroundings including the lights, weather, and range of temperature Celsius. Among the energy sources, the conversion of mechanical energy from ambient vibrations into electrical energy is particularly effective, due to the ubiquitous presence of vibrations and the relatively higher power density than others (Yingjun Sang, 2012)**.** One of the models that apply the vibration energy is inertial generator. The vibrations is transmit to inertial mass through the inertial frame that causing the produce of a relative displacement the frame and inertial mass, m. This system may have a fixed resonant frequency that should be match with the characteristic frequency of the vibrations. Commonly the system of inertial generators modeled as second-order spring and mass system. The Figure 2.1 show the example of this system which based on seismic mass, m and on stretched spring.

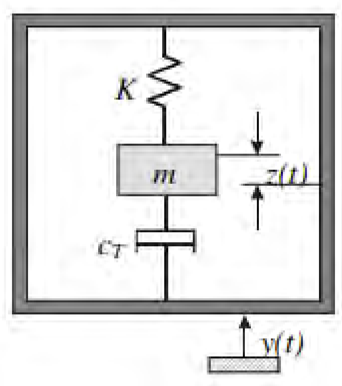

Figure 2.1: Illustrations for inertial generator

The loss of energy during the operation of the system is represented by the damping coefficient, C_T . The damper expressed as two parts which one is for mechanical damping and the other one is the electrical damping (Tan, 2011). All these components is related to the inertial frame which will be excited the by vibration of external sinusoidal in form of $y(t) = Y\sin(\omega t).$ There will be resulting of net displacement, $z(t)$ among the mass and the frame. This is because when the structure of the system vibrate at resonance, the external vibration is out of phase.(pg95/sbeeby). By assuming the mass of vibration source is substantially more than the seismic element and the external excitation is harmonic, the differential equation of motion is:

$$m\ddot{z}(t) + c\dot{z}(t) + kz(t) = -m\ddot{y}(t) \ldots\ldots (1)$$

As the energy is extracted from the relative movement between the mass and the inertial frame, the related equations applied are as following:

$$z(t) = \frac{\omega^2}{\sqrt{\left(\frac{k}{m}-\omega^2\right)^2+\left(\frac{c_T}{m}\right)^2}} Y\sin(\omega t - \emptyset) \ldots\ldots (2)$$

where Y is the amplitude of vibrations while $\emptyset$ is the phase angle is as equation below:

$$\emptyset = \tan^{-1}\left(\frac{c_T\omega}{(k-\omega^2 m)}\right) \ldots\ldots (3)$$

Noted that, the maximum energy that being extracted when the excitation frequency, ω is equal to the value of resonant frequency of the system, ω_n which expresses as:

$$\omega_n = \sqrt{\frac{k}{m}} \ldots\ldots (4)$$

Noted that, the power being dissipated within two parts of damper is (William pg 96):

$$P_d = \frac{m\zeta_T Y^2\left(\frac{\omega}{\omega_n}\right)^3\omega^3}{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2+\left[2\zeta_T\left(\frac{\omega}{\omega_n}\right)^2\right]^2} \ldots\ldots (5)$$

where the total damping ratio, ζ_T is express by $\zeta_T = \frac{C_T}{2m\omega_n}$ …….(6)

Whenever the device is driven at its resonant frequency, ω_n, the maximum power achieved (Stephen Beeby, 2010) . Therefore the output power as below:

$$P_d = \frac{mY^2{\omega_n}^3}{4\zeta_T} \ldots\ldots (7)$$

or by uses excitation acceleration, $A = {\omega_n}^2\, Y,$ the output power express as :

$$P_d = \frac{mA^2}{4\omega_n \zeta_T} \ldots\ldots(8)$$

which explained that the output power is directly proportional to the mass and square of excitation acceleration while inversely proportional to the resonant frequency and damping.

2.3 Piezoelectric

One of the methods of energy harvesting which commonly applied today is through piezoelectric behavior. Piezoelectric material able to convert the mechanical energy based vibrations into the electrical energy by only setting up a simple structure. It is also known as a self-power source or wireless sensor network system (Heung Soo Kim, DECEMBER 2011). It is first discovered by Pierre and Jacques Curie in1880 (Tan, 2011).Piezoelectric contain dipoles. That's why when it is subjected to mechanical force (vibrations), the material of the piezoelectric becomes electrically polarized which in electrical energy. Alerted that, the polarization of piezoelectric is proportional to the strain that being applied. Piezoelectric energy harvester can operates in two modes which are d_{31}mode and d_{33}mode as shown in Figure 2.2 (Tan, 2011):

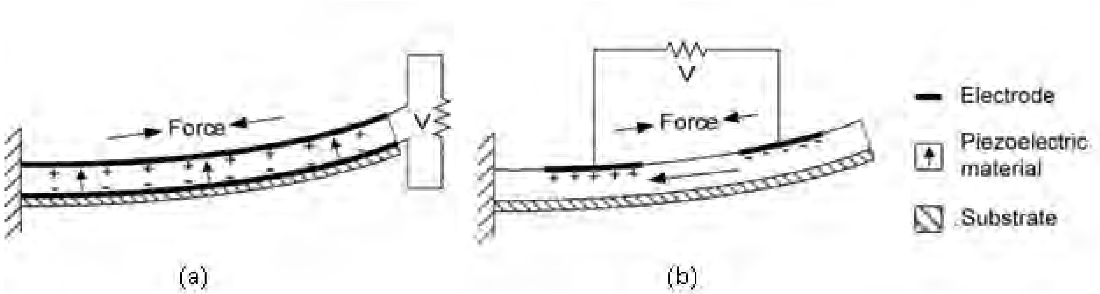

Figure 2.2: Piezoelectric mechanism with (a) $\boldsymbol{d_{31}}$mode and (b) $\boldsymbol{d_{33}}$

During moded_{31}, there is applied of lateral force in perpendicular direction with the direction of polarization as shown in Figure 2.2(a). Inversely, the mode d_{33}have applied of force that is in the same direction with the polarization direction as shown in Figure 2.2(b). Even the piezoelectric materials in d_{31}have a lower coupling coefficients than mode of d_{33},the d_{31}mode is usually used (Anton, 2007). The reason is that, whenever the piezoelectric cantilever bends, lateral stress produced more than the vertical stress which it is much easier to couple in d_{31}mode. Piezoelectric harvested energy with higher output voltage but low current level. They are compatible with MEMS as they have such a simple structures. The lifespan of the piezoelectric is a big implication in piezoelectric energy harvesters, as most of them have poor mechanical properties. Regarding the materials, commonly the piezoelectric used PZT-5A,PZT-5H,BaTiO_3, polyvinyllidene flupride(PVDF) (Anton, 2007).Theoretically, PZT-5A generated the most amount of output power which by use same dimensions (Tom J. Kaźmierski& Beeby, 2011).

2.4 Electromagnetic

The energy of electromagnetic started being applied through the developed system of application in bicycle dynamos. Energy is harvested through electromagnetic by collecting the energy from the generated current of coils causing by the variation of magnetic flux induced from the movement of a rigid magnet (Bin Yan, 2010). In other words, a magnetic induction system of electromagnetic is a system that generates power among the coil of wire which is its relative motion with the magnets. The system will cause a change of the magnetic flux through the coil and leads to the generation of a voltage difference towards the ends of the wire coil. Due to the voltage difference, it can be applied to charge any energy-storage device including capacitor. By depending on the size of the system, the magnitude of energy harvested from magnetic induction system might range up to kilowatts (Jonnalagadda, 2007). The properties of the coil itself have effect on the performance of the electromagnetic generator which is the number of turn (N) of coil is related to the wire diameter, winding density and geometry of the coil. Through the expression below, able to define the fill factor ,f related to the area of the wire, $A_{wire}$to the cross sectional of coil, A_{coil}:

$$A_{wire} = \frac{fA_{coil}}{N} \ldots\ldots(9)$$

In other words, can be said that the fill factor affected by tightness of winding, insulation thickness and winding shaped . Commonly, most of the coils are scramble wound that have fill factor from 50% to 60% (McLyman,W.T., 1988). As to determine the properties of the coil, the main factor to be considered is the type of wire used in the coil. Regarding the case of small energy harvester, it is needed for a copper conductor with minimal coil size and maximizing the number of turns,N. Below shows Table 2.1 for fine copper American wire gauge (AWG) number 58 with minimal 10μm in diameter:

Table 2.1 : The table of coil diameter based on AWG number

AWG No.	Copper diameter (μm)	Wire diameter (including insulation) (μm)	Resistance (Ω/m)
58	10	10.6–12.9	0.22
57	11	11.7–14.1	0.18
56	12.5	13.2–16.5	0.14
55	14	14.7–17.8	0.11
54	15.8	16.5–19	0.09
53	17.8	18.5–21.6	0.07
52	20	21.6–25.4	0.056
51	22	24.1–27.8	0.044
50	25	26.7–30.5	0.035
49	28	29.7–33	0.028
48	31.5	32.8–38.1	0.022
47	35.6	36.8–43.2	0.017

2.5 Hybrid Energy Harvesting

Mat Ali, Noraini and Mustapha, Ain Atiqa and Kok, Swee Leong (2013) in their article mention that in order to enhance the output power from vibration energy, hybrid energy harvester is proposed which combines piezoelectric and electromagnetic micro generator (Mat Ali,2013,). The combinations mean that whenever the hybrid energy harvester generated, the total energy harvested indicates the sum of energies generated from piezoelectric and electromagnetic mechanism. In addition, the total energy harvested from such a coupled technique is the sum of the energies generated from the piezoelectric and electromagnetic mechanisms (Vinod R Challa, M G Prasad and Frank T Fisher, 2009).