ANALYSIS OF ELECTROMAGNETIC ENERGY HARVESTER FOR VARIOUS LENGTH OF BEAM

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ABSTRACT

Energy harvesting is presented by the conversion of ambient mechanical energy into usable electrical energy. Compared with energy stored in such as batteries which is common storage elements, the environments represent a relatively inexhaustible source. In this study, there are two objectives that need to achieve. The first objective is to design an electromechanical energy harvester based on beam structure and analysis the effect of various length of beams to the voltage produced by the energy harvester. For the scope of research in this study is to see the relationship between frequencies and the amount of electricity produced, design a small size of energy harvester, beams are limited 3 length and outputs are presented on LCD and computer based. In this study, energy harvesting from the electromagnetic that produce magnetic field converts mechanical energy to electrical energy. Based on basic operating principles, magnetic flux produced when there are movements of the magnet through the coils. In this study, fabricate an electromagnetic energy harvester is the first step and make the experiment for three different length which is 9 cm, 11 cm and 13 cm. Frequency that use during experiment in range 100 Hz to 500 Hz. Result from the experiment are 9 cm (0.614211 V), 11 cm (0.69845 V) and 13 cm (0.915395 V). For the conclusion, this experiment succesfully achieve the main objective of this project study. To design an electromechanical energy harvester based on beam structure and make analysis about the effect of various length of cantilever beams to the voltage produced by the energy harvester. Important recommendation in this study is the range of the frequency should used frequency in range 10 Hz until 50 Hz, scaling down the dimensions of the proposed structure and to see its feasibility to be used in very low-power micro systems, the mass of the coil should be large as possible within the available volume of the device to generate higher amount of voltage and make a simulation using Finite Element Analysis (FEA). Applications in this study such as medical implants and embedded sensors in buildings and similar structures are just a few of many examples.

ABSTRAK

Penuaian tenaga dikemukakan oleh penukaran tenaga mekanikal kepada tenaga elektrik yang boleh digunakan. Berbanding dengan tenaga dalam yang tersimpan seperti bateri adalah elemen penyimpan yang lazim, persekitaran mewakili sumber yang tidak habis-habis. Dalam kajian ini, terdapat dua objektif yang perlu dicapai. Objektif pertama adalah untuk merekabentuk tenaga elektromagnetik penuai berdasarkan struktur rasuk dan menganalisis kesan panjang pelbagai rasuk untuk voltan yang dihasilkan oleh penuai tenaga. Untuk skop penyelidikan dalam kajian ini adalah untuk melihat hubungan antara frekuensi dan jumlah voltan yang dihasilkan, merekabentuk saiz tenaga penuai yang kecil, rasuk adalah terhad kepada 3 panjang dan jumlah elektrik dibentangkan pada LCD dan berasaskan komputer. Dalam kajian ini, pengambilan tenaga dari elektromagnet yang menghasilkan medan magnet menukar tenaga mekanikal kepada tenaga elektrik. Berdasarkan prinsip-prinsip operasi asas, fluks magnet yang terhasil apabila terdapat pergerakan magnet melalui gegelung. Dalam kajian ini, merekabentuk tenaga elektromagnetik penuai adalah langkah pertama dan membuat eksperimen menggunakan tiga panjang yang berbeza iaitu 9 cm, 11 cm dan 13 cm. Frekuensi yang digunakan semasa eksperimen dalam julat 100 Hz hingga 500 Hz. Hasil daripada eksperimen adalah 9 cm (0.614211 V), 11 cm (0.69845 V) dan 13 cm (0.915395 V). Untuk kesimpulan, eksperimen ini berjaya mencapai objektif utama kajian projek ini merekabentuk sebuah penuai tenaga elektromekanik berdasarkan struktur rasuk dan membuat analisis tentang kesan panjang rasuk yang pelbagai kepada voltan yang dihasilkan oleh penuai tenaga. Syor penting untuk masa hadapan dalam kajian ini adalah julat frekuensi yang digunakan dalam julat 10 Hz hingga 50 Hz, mengkaji dimensi struktur yang dicadangkan dan untuk melihat kemungkinan kuasa sistem mikro digunakan sangat rendah, jisim gegelung besar yang mungkin dalam jumlah yang ada untuk menjana jumlah voltan yang lebih tinggi dan membuat simulasi menggunakan “Finite Element Analysis (FEA)”. Aplikasi dalam kajian ini seperti implan perubatan, sensor yang tertanam dalam struktur bangunan yang sama dan beberapa contoh yang berkaitan dengan elektromagnetik penuai tenega untuk menghasilkan voltan.

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m	The Seismic Mass
c	The Damping Constant
k	The Spring Constant
z(t)	The Spring Deflection
y(t)	The Input Displacement
σ	Stress
ν	Poisson's Ratio
E	Young's Modulus
δ	Deflection
L	The Beam Length
t	Cantilever Thickness
w	Resonance Frequency
e	Voltage Or Electromotive Force
Ø	The Magnetic Flux
N	Turn Of Coil
V	Volt
Hz	Hertz
I	Inductance
R	Resistance
f	Frequency

LIST OF ABBREVIATIONS

FEA	Finite Element Analysis
PC	Personal Computer
LED	Light Emission Diode
LCD	Liquid Crystal Display
MEMS	Micro-Electromechanical Systems
NdFeB	Neodymium Iron Boron
SIMO	Signal Multi-Output
SISO	Signal Single-Output
Viso	Voltage Of Sinusoidal Signal
DAQ	Data Acquisition System

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Electromagnetic induction was discovered by Faraday in 1831. The electric current in a conductor located within a magnetic field. The conductor made from a coil and the electricity is generated either the relative movement of the magnet and coil or because of the changes in the magnetic field. The amount of electricity generated depends on the strength of the magnetic field, the velocity of the relative motion and the number of turns of the coil.

Developement in micro electromechanical systems (MEMS) has the point where its applications to a wide range of areas are now very important for the future. MEMS applications such as medical implants and sensors in buildings. The supply of power to such systems has so far been through by a batteries. In long lived systems where battery replacement is difficult and generating power from ambient sources will becomes imperative. Systems that depend on batteries have a limited operating life while systems having their own self-powered supply unit have a potentially much longer life. Electromechanical systems convert energy from existing energy sources within their environment into electrical energy. An alternative solution to batteries is miniature renewable power supply units.

1.2 PROJECT BACKGROUND

Our approach is to use mechanical vibration as the ambient energy source for electrical power generator. In this project, a vibration based on magnet and coil power generator is being study and fabricate. The size of the device is small, mechanical resonances tend to increase in frequency and it is the challenge of generating power from the conversion vibration enrgy must be high as possible. The performance of the proposed energy harvester structure is verified through study, theory and it is shown that the Micro-Electromechanical Systems (MEMS) structure can be used as an energy-harvesting device for low frequency applications. In order to have an idea about the effect of scaling down the dimensions on the performance of the energy harvester, testing method is developed in the frame of this further study. For this method, a cantilever beam length scaling factor is proposed and the dimensions of the devices to be tested are arranged according to this factor. It should be noted that the thickness of the cantilever and the coil wire diameter are kept constant respectively but the length of each beam is difference in this study. In principle, either the magnets or the coil can be chosen to be mounted on the beam while the other remains fixed. It is generally preferable, the magnets that attached to the beam can act as the inertial mass. This is one of the most effective methods for energy harvesting to produce electromagnetic induction by means of permanent magnets, a coil and a resonating cantilever beam.

1.3 PROBLEM STATEMENT

The effect of the cantilever length on the performance of the harvester is investigated. We measured and calculated resonance frequency and maximum peak induced voltage for the electromagnetic energy harvester that have 4.5 mm wide cantilever and two cascaded magnets. Electromagnetic energy harvester will test for a certain range vibration frequency which 100 Hz until 500 Hz for different cantilever beam lengths. The most important parameters influencing the design of such a system are its beam length and it conversion energy efficiency. Number of length beam increase, excitation increase and output voltage increase. The size is dependent on the energy requirement and must be as small as possible. So that it will be compatible with the general design objectives of MEMS. This project also investigates the optimal coil turns for an electromagnetic power harvester. Turn coils giving an effect to the power generation. Theoretically, the power harvested increases proportionally with the radius and turn of the coil wire. Power generated by the system is proportional to the voltage induced. Number of turn of coil increase, magnetic flux increase, induced voltage increase.

1.4 OBJECTIVES

This project objective consists of:

1. Design an electromechanical energy harvester based on beam structure.
2. Analysis the effect of various length of beams to the voltage produced by the energy harvester

1.5 SCOPE RESEARCH

The scopes of the project are limited to:

1. The relationship between frequencies and the amount of electricity produced.
2. Design a small size of energy harvester.
3. Beams are limited 3 length.
4. Outputs are presented on LCD and computer based.

1.6 CHAPTER OUTLINE

This report project is organized into five chapters. Each chapter will explain in detail to complete my project whether in experiment or theoretical. The first chapter will discuss about the project background, problem statement, project objective and the scope of the project.

Chapter 2 will reviews some theory about energy harvester in many aspects and the previous study about electromagnetic energy harvester. Analysis the effects of cantilever beam with various length and turn of coil an electromagnetic energy harvester is also explained in this chapter.

Chapter 3 presented the research methodology, the model design, the procedures to complete my project and application tool that have been used in this project.

Chapter 4 views the result of the amount electricity will produced in electromagnetic energy harvester and discussion of the overall result. Analysis about the output power, output voltage, coherence graph and its relation with natural frequencies is also discussed in this chapter.

In final chapter, the project report is summarized and some recommendation works are given to improve the project for future planning.

CHAPTER 2

LITERATURE REVIEW

The purpose of this chapter is to provide a review of past research efforts related to micro energy harvester. A review of other relevant research studies is also provided. Literature has been studied on theory, vibration source, and type of energy harvester. Little information can be found on integrated evaluation methods. The review is organized according to this study to offer insight on how past research efforts have laid the groundwork for subsequent studies and include the present research effort. The review is study in detail so that the present research effort can be properly tailored to add to the present body of literature so that it will follow the scope and direction of the present research.

Energy harvesting approaches transform light, heat and kinetic energy available in the sensor environment into electrical energy and can offer the potential of renewable power sources which can be replace the battery. It devices scavenge energy from the environment such as ambient forced excitation, flow induced vibration, wind power and electromagnetic energy harvester is the oldest techniques for energy harvesting. There are few methods and studies have been conducted to increase the performance and the amount of electricity to make sure utilization can be improved. The subject in this paper refer to the kinetic energy generator which converts mechanical energy in the form of vibrations into electrical energy. Kinetic energy is typically converted into electrical energy using electromagnetic, piezoelectric or electrostatic transduction mechanisms.

2.1 INTRODUCTION

The ambient vibrations has long been known and the energy produce from ambient vibrations was too small for almost all applications for four decades ago. The advancement of technology, increasing needs for energy and limitations of other energy sources have been changing the feasibility calculations. There has been a significant effort in the research community, government agencies and private companies to generate electricity from the oscillations.

Advances in technology led to the development of electronic circuits and sensors with extremely low electricity consumption. It is possible to operate these devices accurately by using the energy harvested from ambient vibrations. These advances in technology also reduced the cost of manufacturing for large structures. Many technologies are available to make metals resistant to harsh operating conditions and corrosion. There are many ways to convert mechanical energy into electricity including hydraulic systems, piezoelectric materials and power generators.

The development of microelectromechanical systems (MEMS) has highlighted a wide range of applications for miniature sensors and actuators. This has made it possible to implant microsensors and actuators into a whole host of different structures for applications such as medical implants, embedded sensors in buildings and bridges. A promising alternative to batteries is miniature self-contained renewable power supplies. Renewable power supplies convert energy from an existing source within their environment into electrical energy. The sources of energy available will depend on the application.

2.2 GENERAL THEORY OF KINETIC ENERGY HARVESTING

Kinetic energy harvesting requires a transduction mechanism to generate electrical energy from motion and the generator will require a mechanical system that couples environmental displacements to the transduction mechanism. The design of the mechanical system should maximize the coupling between the kinetic energy source and the transduction mechanism and will depend entirely upon the characteristics of the environmental motion.

Vibration energy is best suited to inertial generators with the mechanical component attached to an inertial frame which acts as the fixed reference. The inertial frame transmits the vibrations to a suspended inertial mass producing a relative displacement between them. A system will possess a resonant frequency which can be designed to match the characteristic frequency of the application environment. These approaches magnify the environmental vibration amplitude by the quality factor of the resonant system and this is discussed further in the following section.

The transduction mechanism itself can generate electricity by exploiting the mechanical strain or relative displacement occurring within the system. The strain effect utilizes the deformation within the mechanical system and typically employs active materials such as piezoelectric. In the case of relative displacement, either the velocity or position can be coupled to a transduction mechanism. Velocity is typically associated with electromagnetic transduction whist relative position is associated with electrostatic transduction. Each transduction mechanism exhibits different damping characteristics and this should be taken into consideration while modeling the generators.

The mechanical system can be increased in density, for example by including a hydraulic system to magnify amplitudes or forces, or couple linear displacements into rotary generators. The output presents the maximum power available in a resonant system. This is based upon a conventional second-order spring and mass system with a linear damper and is most closely suited to the electromagnetic case, since the damping mechanism is proportional to velocity. The general analysis, however, still provides a valuable insight into resonant generators and highlights some important aspects that are applicable to all transduction mechanisms.

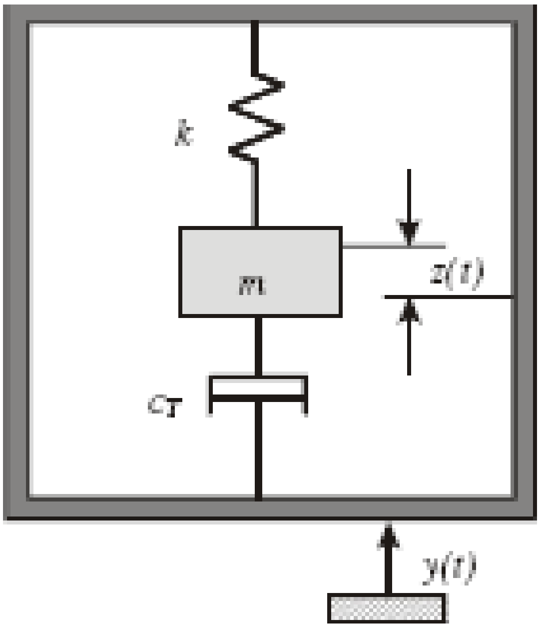

Figure 2.2 : Inertial Generator

Source: [C.B. Williams, 1995]

Inertial-based generators are essentially second-order, spring-mass systems. Figure shows a general example of such a system based on a seismic mass, m, on a spring of stiffness, k. Energy losses within the system are represented by the damping coefficient, c. These components are located within the inertial frame which is being excited by an external sinusoidal vibration of the form y(t) = Y sin(ωt).This external vibration moves out of phase with the mass when the structure is vibrated at resonance resulting in a net displacement, z(t), between the mass and the frame. Assuming that the mass of the vibration source is significantly greater than that of the seismic mass, not affected by its presence and also that the external excitation is harmonic. The differential equation of motion is described as [C.B. Williams, 1995](1)

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

Where:

m= the seismic mass

c= the damping constant

k= the spring constant

z(t)= the spring deflection

y(t)= the input displacement

Provided sufficient acceleration is present, increased damping effects will result in a broader bandwidth response and a generator that is less sensitive to frequency. Excessive device amplitude can also lead to nonlinear behaviour and introduce difficulties in keeping the generator operating at resonance.

It is clear that both the frequency of the generator and the level of damping should be designed to match a particular application in order to maximize the power output. Furthermore, the mass of the mechanical structure should be maximized within the given size constraints in order to maximize the electrical power output. It should also be noted that the energy delivered to the electrical domain will not necessarily all be usefully harvested.

Since the power output is inversely proportional to the natural frequency of the generator for a given acceleration, it is generally preferable to operate at the lowest available fundamental frequency. This is compounded by practical observations that acceleration levels associated with environmental vibrations tend to reduce with increasing frequency. Application vibration spectra should be carefully studied before designing the generator in order to correctly identify the frequency of operation given the design constraints on generator size and maximum permissible z(t).

2.3 EFFECT OF CANTILEVER BEAM IN MEMS

Cantilevered beams are the most ubiquitous structures in the field of microelectromechanical systems (MEMS). MEMS cantilevers are commonly fabricated from silicon (Si), silicon nitride (Si3N4), or polymers. The fabrication process typically involves undercutting the cantilever structure to release it, often with an anisotropic wet or dry etching technique. Without cantilever transducers, atomic force microscopy would not be possible. A large number of research groups are attempting to develop cantilever arrays as biosensors for medical diagnostic applications. MEMS cantilevers are also finding application as radio frequency filters and resonators. The MEMS cantilevers are commonly made as unimorphs or bimorphs.

Two equations are key to understanding the behavior of MEMS cantilevers. The first is Stoney's formula, which relates cantilever end deflection δ to applied stress σ:

$$\delta = \frac{3\sigma(1-v)}{E}\left(\frac{L}{t}\right)^2 \qquad (2)$$

where ν is Poisson's ratio, E is Young's modulus, L is the beam length and t is the cantilever thickness. Very sensitive optical and capacitive methods have been developed to measure changes in the static deflection of cantilever beams used in dc-coupled sensors.

The second is the formula relating the cantilever spring constant k to the cantilever dimensions and material constants:

$$k = \frac{F}{\delta} = \frac{Ewt^3}{4L^3} \qquad (3)$$

where F is force and w is the cantilever width. The spring constant is related to the cantilever resonance frequency w_0 by the usual harmonic oscillator formula $w_0 = \sqrt{\frac{k}{m}}$.. A change in the force applied to a cantilever can shift the resonance frequency. The frequency shift can be measured with exquisite accuracy using heterodyne techniques and is the basis of ac-coupled cantilever sensors.

The principal advantage of MEMS cantilevers is their cheapness and ease of fabrication in large arrays. The challenge for their practical application lies in the square and cubic dependences of cantilever performance specifications on dimensions. These superlinear dependences mean that cantilevers are quite sensitive to variation in process parameters. Controlling residual stress can also be difficult.

2.4 THE MAGNETIC FIELD AND FARADAY'S LAW

Faraday law is a law that states an electric field is induced in any system in which a magnetic field is changing with time [Giorgio Rizzoni, 2007]. The generated voltage or induced electromotive force, emf (e) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit. In the other word, the emf generated is proportional to the rate of the magnetic flux. The induced voltage represents

$$e = -\frac{d\emptyset}{dt}\ (volt) \qquad (4)$$

Where:
V @ e = voltage or electromotive force
Ø = the magnetic flux (Weber's, Wb)
t = time (sec)

The coil is used to flow the current such a way that the magnetic flux generated by the current would oppose the increasing flux. In practical applications, the size of the voltages induced by the changing magnetic field can be significantly increased if the conducting wire is coiled many times around. So as to multiply the area crossed by the magnetic flux lines many time over. The induced voltage in the coil could be approximated by the following expression:

$$e = N\frac{d\emptyset}{dt}\ (volt) \qquad (5)$$

Where:
N = turn of coil