DEVELOPMENT OF LOW FREQUENCY ELECTROMAGNETIC VIBRATION ENERGY HARVESTER

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2016

DEVELOPMENT OF LOW FREQUENCY ELECTROMAGNETIC VIBRATION ENERGY HARVESTER

by

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Thesis submitted in fulfilment of the requirements

for the degree of

Master of Science

June 2016

ACKNOWLEDGEMENTS

Alhamdulillah, my highness praises and thanks to Allah SWT, who gives me the patience, strength, knowledge and courage to complete this research.

I would like to express my gratitude to my supervisor Prof Dr. Zaidi B Mohd Ripin, who has never given up correcting the mistakes I made, has encouraged me to broaden my viewpoint, and taught me the meaning of the life. His patience and dedication in directing me on the way to success, and his goal of providing a reliable research working environment encouraged me to keep going.

I also want to extend my gratitude to the technicians especially Mr. Wan Mohd Amri, Mr. Jamaluddin Che Amat and my research partner, Mr Izzudin bin Alisah who work with me for the experimental and measurement work. Apart of that, I want to thank to all my fellow friends from Vibration laboratory whose give their help, moral support and some valuable hints for completing my research.

Besides that, a special thanks to Collaborative research in Engineering, Science and Technology Centre (CREST), for providing a fund for this research project. In addition, a special gratitude to National Instruments (NI) for their help and guide us the knowledge of data acquisition and equipment.

Last but not least, I would like to express my deepest gratitude to my husband, Mr Mohd Taufik bin Abd Hamid, my daughter Nur Madihah binti Mohd Taufik and my whole family for their kindly love and continuous support during my intricate times in completing this research.

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LIST OF ABBREVIATIONS

AC	Alternating Current
CAD	Computational Aided Design
DC	Direct Current
DDHO	Driven Damped Harmonic Oscillation
EM	Electromagnetic
EMF	Electromotive force
FFT	Fast Fourier Transform
FRF	Frequency Response Function
mFCUP	Micro mechanical frequency up conversion
MEMs	Micro electro mechanicals
NDFeB	Neodymium magnets
PFIG	Parametric frequency increased generator
PZT	Material of zirconatetitanate of piezoeletric
PVDF	Polyvinylidinefluoride
RF	Radio energy
TPMS	Tire pressure monitoring systems
VCA	Voice coil actuator
VEH	Vibration Energy Harvesting
VEMF	Back electromotive voltage
WSN	Wireless Sensor Network

LIST OF SYMBOLS

A	Surface Area of the coil
$A(\omega)$	Calculated acceleration (radian per second)
B	Magnetic field
c_T	Total Damping coefficient
c_e	Electrical damping coefficient
c_m	Mechanical damping coefficient
f	Frequency
F	Force
$F_{lorentz}$	Lorentz force
i	Electrical Current
k	Stiffness spring
K_f	Force constant parameter
K_b	The back electromotive force parameter
l	Length
L_{coil}	Inductance of coil
n	Number of the turns in the coil
Φ	Magnetic flux
P_{mean}	Mean power
R_{coil}	Internal coil resistance

R_{load}	Load Resistance
$V_{emf,back}$	Electromotive force voltage
$\dot{x}$	Velocity
w	width
ω	Base excitation frequency
ω_n	Natural frequency
ζ	Damping ratio

PEMBANGUNAN PENJANA TENAGA ELEKTROMAGNET GETARAN BERFREKUENSI RENDAH

ABSTRAK

Tesis ini membentangkan pembangunan penjana tenaga getaran berdasarkan sistem elektromagnet yang menjana tenaga getaran yang berfrekuensi rendah pada struktur jambatan. Tujuan kajian ini adalah untuk menjana tenaga bagi penderia tanpa wayar. Penjana elektromagnet difabrikasi menggunakan empat unit penggerak gegelung suara yang dibuat daripada magnet Neodymium dan gegelung tembaga. Voltan maksimum 2.6 V dan kuasa maksimum 25 mW telah dihasilkan oleh penjana elektromagnet pada frekuensi 10 Hz dan pecutan 0.35g. Model penjana dibina dengan menggabungkan sistem mekanikal jisim-pegas-peredam dan sistem elektromagnetik yang menghasilkan arus akibat gerakan mekanikal gegelung. Keputusan simulasi menunjukkan perbandingan yang baik dengan eksperimen pada julat frekuensi 4Hz - 10 Hz untuk satu unit penjana mempunyai perbezaan sebanyak 4.3%. Sumbangan utama dalam kajian ini adalah pembinaan prototaip sistem penjana tenaga getaran yang rendah dan pembangunan model simulasi dalam Simulink. Ketumpatan kuasa system penjana adalah 602 µW/g.cm^3 dan 1308.2 µW/g.cm^3 pada 4 Hz dan 10 Hz dan cukup berupaya untuk menghidupkan peranti penderia tanpa wayar.

DEVELOPMENT OF LOW FREQUENCY ELECTROMAGNETIC VIBRATION ENERGY HARVESTER

ABSTRACT

This thesis presents the development of an energy harvester based on electromagnetic system to harvest energy from the low frequency vibration in particular structural vibration of the bridge. The eventual intended application is to power up a wireless sensor node that can be used to monitor structural integrity of a bridge. The electromagnetic vibration energy harvester is developed with four units of voice coil actuators using Neodymium magnets and copper coils. An open circuit voltage of 2.6 V and maximum output power of 25 mW were generated at 10 Hz under constant acceleration of 0.35g respectively. A model of the harvester is made by combining the mechanical of mass-spring-damper system with the electromagnetic resistance and inductance where the velocity of the moving coil from the mechanical system will produce current in the system. The simulation model showed a good agreement with the experimental results at 4 - 10 Hz for one cell harvester with 4.3% difference. The main contribution of this research is the prototype construction of low vibration energy harvester system and development of the energy harvester model using Simulink. The power density of the harvester system is 602 µW/g.cm^3 and 1308.2 µW/g.cm^3 at 4 Hz and 10 Hz respectively and enough to power up the wireless sensor network device.

CHAPTER 1

INTRODUCTION

1.1 Background on energy harvesting

Energy harvesting is the process of acquiring the energy from environment and converting into usable electrical energy to provide power for electronic devices (Roundy et al. 2003). It has been developed and widely used by many researchers in this decade due to the environmental and economic reasons.

There are several energy sources which are widely used including kinetic energy (waves, wind, gravity and vibration), electromagnetic energy (radio frequency (RF), photovoltaic), thermal energy (solar indoor and outdoor, temperature differential, combustion), biological and chemical energy (biofuels, biomass) or nuclear energy (radioactive decay) (Sari et al. 2009 and Matiko et al. 2014).

Energy can be harvested from the ambient environment using several transducers. Transducer is a device that converts ambient energy into electrical energy. Three transducers most widely reported in vibration energy harvesting are piezoelectric which is a special materials that can be produce electricity when subjected to load, electrostatic which is based on the variable capacitors to extract the energy and electromagnetic which is based on the electromagnetic induction to produce the voltage from the motion of coil and magnet.

1.2 Energy harvesting from bridge structures

Wireless monitoring of civil engineering structures such as bridges and overpasses has gained a lot of interest in the recent years (Ntotsis et al. 2009).The application of sensor node has been extensively used for the measurement of the vibrations in order to generate the appropriate power. In order to monitor the structural damage to the bridge, the strain level must be measured and recorded typically using wireless sensor.Wired connection system is generally used for monitoring the bridge vibration (Wang et al., 2006). However, this wiring involves considerable cost, maintenance and difficulty of installation of the sensor (Lynch et al. 2003). In California, the total cost for the bridge is $300 000 for 60 accelerometers where $5000 is spent for each the installed sensor (Li et al. 2011). The batteries are used to power the wireless system. However, these have to be replaced and scheduled frequently (Arroyo et al. 2012).

The researchers consider another solution for the battery alternative for powering of wireless sensor nodes which is based on harvesting the available vibration energy and converting it into electric power.

Vibration harvesting was the focus of this study because the standard operating conditions of bridge structure often produced a low level vibration spectrum. The typical structures have basic vibration level that occur at frequencies less than 5Hz (Beeby et al. 2006) and had input acceleration (peak less than ± 0.2g).Therefore, there is a need to develop vibration energy harvester to work in the frequency range of fundamental structure of models.

1.3 Problem Statement

The bridge structures have to be monitored periodically to ensure structural integrity. Several techniques exist to monitor an infrastructure, for example a conventional resistive strain gauging, embedded or attached optical fibre sensors, accelerometers and linear variable displacement transducer (Coolins et al., 2014). It is very challenging to harvest since the bridge vibration has low amplitude and frequencies. Application of the Wireless sensor network is more preferable because the wired sensors are weak, expensive to install and to maintain. However, the main issue of implementing wireless sensor is the limited battery life. The battery used need to be replaced, difficult to dispose and less energy capacity lifetime (Galchev et al., 2011). An alternative approach to the battery for powering the monitoring system of the structure system is by harvesting the vibration energy from the bridge structures.

There are many different designs of harvester and it is difficult to select the optimal design for vibration energy harvesting. This is because the vibration source is often nondeterministic in nature and contains impulse and other non-uniformity (Spreeman et al., 2008). In addition, most harvesters in the literature operate at frequencies of more than 30Hz, including many harvesters based on piezoelectric, electrostatics and electromagnetic energy conversion (Gu and Livermore, 2011). The aim of this research is to develop vibration energy harvester frequency of low frequency at range of 10Hz and below which is to provide perpetual power for wireless sensor network on the bridge structures.

1.4 Objectives

The main objectives of this work are

- To develop an energy harvester based on electromagnetic system in order to harvest energy at low frequency at range 4 to 10 Hz.
- To construct the model based on the governing equations of electromagnetic system and simulated in Matlab Simulink in order to characterize the energy harvester system.
- To determine the generating of voltage and power on different frequencies, vibration amplitudes and load resistors.

1.5 Research Contributions

The first contribution of this research is the model construction of low vibration energy harvester system which can be expanded for a higher power system. A second contribution is the development of simulation model of low frequency vibration energy harvester using Matlab Simulink.

1.6 Scope

This research is focused on the modelling and experiments for electromagnetic vibration energy harvester for low vibration energy harvester for frequency of 10Hz and below. The study is limited to the construction of vibration energy harvester consisting of four cells. The experiments also limited until the load power only. The range of low frequency is 4Hz to 10Hz and only employ for the bridge structure application.

1.7 Thesis Outlines

The following is a brief overview of each chapter of this thesis, which illustrates the sequence of tasks required to develop the vibration energy harvester for the bridge.

Chapter 1 presents consists of brief introduction of the thesis, problem statement, objectives, contribution and scope of the research. The background information on energy harvesting and WSN technologies, technical benefits, and bridge applications is described.

Chapter 2 describes comprehensive literatures on the vibration energy harvesting device. Piezoelectric, electromagnetic and electrostatic energy harvesters developed by researchers are discussed in depth. This section summarized the application and characterization of the low frequency vibration energy harvesting technologies.

Chapter 3 fully describes the proposed electromagnetic vibration energy harvester system. It explains the concepts and development by analytical modelling, prototyping, fabrication and experimentation of energy harvester system. This chapter ends with the summary of the performance for the proposed electromagnetic vibration energy harvester.

Chapter 4 describes the model development of the electromagnetic vibration energy harvester in Simulink software.

Chapter 5 explains the result and discussion of the proposed electromagnetic vibration energy harvester system.

Chapter 6 contains a summary of the work and conclusion as well as future work.