SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant and Maintenance)"

Signature	: ....
Supervisor	: Dr. Roszaidi Bin Ramlan
Date	: 19/05/2015

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RESEARCH VIRATION ON WIDEBAND LINEAR RESONANT GENERATOR ENERGY HARVESTING DEVICE FOR REMOTE SENSING APPLICATIONS

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This report is submitted as to fulfill the

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature : ....

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Date : 19/5/2015

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Dedicated to Mum and Dad

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ABSTRACT

Vibration energy harvesting is an attractive technique for potential powering of wireless sensor and low power devices. But, in research showed that most harvesters are work efficiently only with limited bandwidth near their resonant frequencies. Thus, strategies to increase the bandwidth of the vibration energy harvesters become one of the most critical issue before these harvesters can be widely deployed in practical. This report represents the linear resonant device, a electromagnetic energy harvester that can convert transverse vibration energy to electrical energy. It will first introduced with analytical study and the solutions that have been done by past researchers. Next, for the methodology, the method used for conducting the experiment is electromagnetic. The apparatus are mainly consists of a steel beam, a permanent magnets, copper coils, voltmeter, resistor decade box, shaker and analyzer. There are four types of experiments which including free vibration, quasi-static experiment, dynamic testing and calculation for the maximum power harvested among various resistance. The solution to widen the bandwidth is by altering the resister of the system. The power harvested is calculated and it shows that 50 Ω of resistance produced the highest power but not 200 Ω. In addition, the main problem in this experiment is that excitation frequency of 20 Hz was not able to produce any voltage at all. The 40 mm of steel beam was also gave the wrong data and results. The reasons were analyzed and investigated and discuss in the report. On the other hand, 36 mm of steel beam gave the best result as the linear generator successfully to wide its band obviously and it also showed that the open circuit reach the highest peak. At last, the trend of the experimental study will be compared with the analytical study of the project.

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LIST OF SYMBOLS

m	=	Mass of electromagnet
M	=	Mass of the beam with mass
kx	=	Spring system
B	=	Damper
c	=	damping coefficient
$c\dot{x}$	=	Damper system
l	=	Length of the beam
w	=	Width of the beam
h	=	Thickness of the beam
E	=	Young's Modulus
L	=	Coil
$v(t)$	=	Load voltage
$y(t)$	=	Base excitation
$z(t)$	=	Displacement of the mass relative to the fixed frame and to the coil

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$F(t)$	=	Applied Force
t	=	Time per cycle
C	=	Number of cycle
Q	=	Quality factor
X	=	Input displacement
Y	=	Output displacement
Z	=	Displacement, amplitude of seismic mass relative to base
K	=	Spring
R	=	Resistance
R_c	=	Internal coil resistance
R_L	=	Load resistance
W_c	=	instantaneous power
P_{ave}	=	Average Power
Z_{max}	=	Maximum extend that mass can moved
$P(W)$	=	Power harvested from the coils
ξ	=	Damping Ratio
ξ_0	=	Unwanted Damping
w_n	=	Natural Frequency
$\emptyset$	=	Phase angle
V	=	Voltage
Ω	=	Ohm

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LIST OF ABBREVIATION

RMS	-	Root Mean Square
LVDT	-	Linear Variable Displacement Transducer
FFT	-	Fast Fourier Transform
SDOF	-	Single Degree of Freedom System

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CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 Background

Energy is everywhere in the environment surrounding us which is available in the form of light energy, thermal energy, wind energy, mechanical energy and so on. From these natural-occurring energy sources, energy can be harvested by the process of capturing the minute amount of energy sources, accumulate and store it, and lastly supply it in a form that can be performed. Nowadays, harvesting energy from vibrations is one of the most promising technologies. The example of vibrations source can be from the floor or wall, machine, tall buildings, ocean waves and even human motions. (Zuo & Tang 2013)

Vibration energy harvesting is an attractive technique for potential powering of wireless sensors and low power devices. While the technique can be employed to harvest energy from vibrations and vibrating structures, a general requirement independent of the energy transfer mechanism is that the vibration energy harvesting

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device operates in resonance at the excitation frequency (Challa *et al*. 2008).So far, the battery is the main power source for sensor applications. But, due to its limited lifespan, expensive cost and also containing harmful chemical, the energy harvesting can become a perfect replacement for delivering power to the sensor applications. This statement is supported by Mitcheson *et al.* (2004) who stated that energy harvesting is a topic of substantial and increasing research attention. He has analyzed practical miniature device to substitute the batteries in medical, and many others for low power applications. On the other hand, we can also classify the main energy harvesting technologies by the hierarchy shown in Figure 1.1 below:

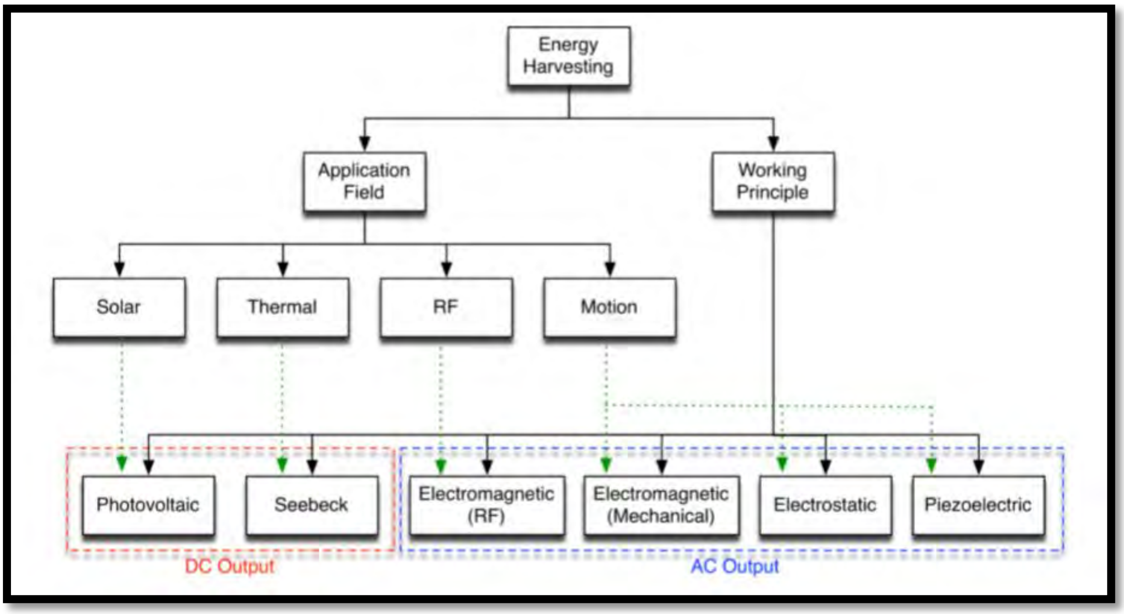

Figure 1.1 Hierarchy of main energy harvesting technologies

(Source : Caliò *et al*., 2014)

In the past experiment, the vibration sources for small scale power generation mostly done by electrostatic, electromagnetic or piezoelectric method. All vibration energy conversion mechanisms use a linear mechanical oscillator to resonate naturally according to the excitation frequency presents in the environment. There are lots of different strategies that have been investigated and reported to develop energy harvesters from low frequency limitations. But, most vibration based energy harvesters are designed as linear resonators that only work efficiently with limited bandwidth near their resonance frequencies. Thus, to increase the bandwidth of

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vibration energy harvesters has become one of the critical issues before these harvesters can widely deployed.

In this project, the research of getting the maximum power of wideband linear resonant generator is investigated and hopefully more ideas can be generated to improve the research from its limitations.

1.2 Problem Statement

Linear energy harvesting device is introduced to convert the vibrations to electrical energy. But, most harvesters are work efficiently only with limited bandwidth near their resonant frequencies. Thus, increasing the bandwidth of the vibration energy harvesters become one of the most critical issues before these harvesters can be widely deployed in practical. Hence, ways to enhance the performance of vibration is the main focus for this research.

1.3 Objective

a) To study the characteristics of a linear resonant generator
b) To fabricate a wideband resonant generator
c) To investigate the performance of the proposed device.

1.4 Scope of Project

The scope of the project involves the theoretical mechanical modelling of the resonant generator using a mass-spring-damper model. A device will be fabricated and experiment will be conducted. The research on what governs the good properties of the resonant generator and also the limitations of the devices will be figure out and analyzed.

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CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

2.1 Background Study

Most vibration-based generators generated the maximum power when the resonance frequency of the generator matches the frequency of the ambient vibration. If there is difference between these two frequencies, it can directly cause in very huge decreased in power output. This issue will limit its performance in real applications.

In recent years, there are lots of research on solutions to overcome the problems of low frequency limitation and narrow bandwidth of the energy harvester device. Research on strategies to the possible solution includes the periodic turning of resonant frequency of the generator so that it matches the frequency of the ambient vibration at all times or by widening the bandwidth of the generators. The periodic tuning can be achieved using mechanical and electrical methods. On the other hand,

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bandwidth widening can be achieved by using a generator array, a mechanical stopper, nonlinear springs and bi-stable structures.

2.2 Limitations of Generator

In research showed that there are two important factors that limit its efficiency which are the narrow bandwidth and low frequency density. In addition, the design of the generator and loss of energy during damping will also affect the overall power output.

Williams & Yates (1995) stated that when the generator operates at the resonance, the power generated is inversely proportional to the transducer damping factor. In principle, when damping factor of zero would generate infinity power at resonance. But, in practical, this is impossible to happen. Thus, the damping factor must be more than zero.

They also concluded that the main limitations on the power output of the generator are its size. Size limits the magnitude of the seismic mass and the maximum distance that the mass can be travel. The greater the size, the higher the power generated. The design rules for optimum power for the design device are:

(i) The mass and extend of the mass should be as large as possible within the available volume of the device.

(ii) The spring, k should be designed so that the resonance frequency of the device matches the vibration frequency of the applications.

(iii) The damping factor should be design small enough to make the mass move to the limits of its range.

(iv) The unwanted damping, ξ_0 should be minimized.

In further research of Stephen (2006), he described that the maximum power is delivered to an electrical loads when its resistance is equal to the sum of the coil internal resistance and the electrical analogue of the mechanical damping coefficient.

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Thus, the coil internal resistance and mechanical damping should be minimized to harvest more energy.

2.3 Frequency Tuning

Zhu *et al*. (2010) defines that the tuning methods can be classified into intermittent (passive) tuning which is the power consumed periodically to tune the device. This approach only consumes power during the tuning operation and uses negligible energy once the generator is matched to the frequency of the ambient vibrations. As for the second one is called the continuous (active) tuning which defined as a tuning mechanism that is continuously applied even if the resonant frequency equals the ambient vibration frequency. As both tuning are compared, continuous tuning consumes more energy than intermittent tuning as it is applied constantly to the generator.

Roundy and Zhang (2005) also concluded that generators using a continuous tuning mechanism can never produce a net increase in the power output as the power required to tune the resonant frequency will always exceed the increase in output power resulting from the frequency tuning. On other words, the intermittent tuning consumes less energy than continuous tuning because it switched off once the device is at resonance.

2.3.1 Mechanical Tuning Methods

Most vibration energy harvesting devices are based on cantilever with a mass shown in Figure 2.1. The mechanism tunings are achieved by changing dimensions, moving the center of gravity of the proof mass, variable spring stiffness and straining the structure.

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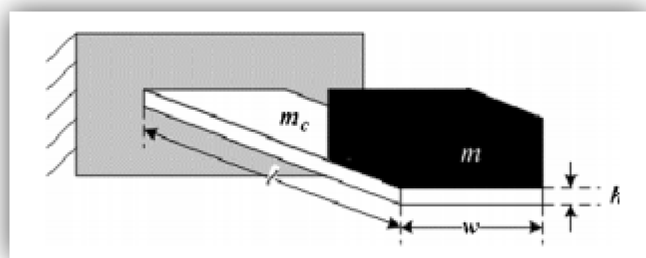

Figure 2.1: Cantilever with a mass (Source: Beeby *et al*., 2006)

(i) Changing the dimensions

The approach requires the cantilever base clamp be released and reclamped in new locations along the length of the beam thereby by changing the effective length. The study showed that the shorter the beam, the higher the normalized resonant frequency.

(ii) Moving the center of gravity of the proof mass

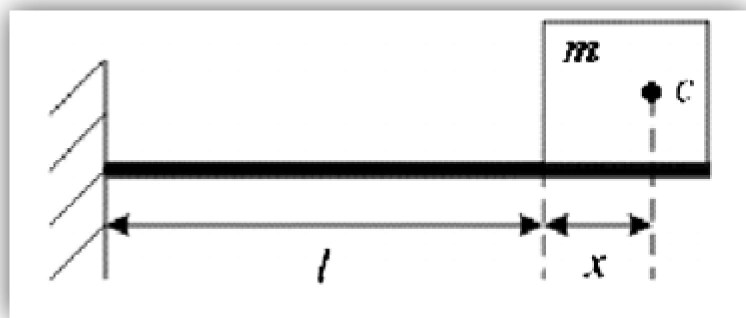

Figure 2.2: Side view of the cantilever structure (Source: Beeby *et al.,* 2006)

The Figure 2.2 showed that the side view of the cantilever structure with a mass on the free end. The further the center of gravity on the proof mass, the lower the resonant frequency.

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