UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

INFLUENCES OF NEODYMIUM MAGNET CONFIGURATIONS ON THE STIFFNESS OF A VIBRATION BASED ENERGY HARVESTING DEVICE

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Master of Science in Mechanical Engineering

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A thesis submitted in fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering

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DECLARATION

I declare that this thesis entitled "Influences of Neodymium Magnet Configurations on the Stiffness of a Vibration Based Energy Harvesting Device" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :……………………………

Name : HILMIAH BINTI A.GHANI

Date :……………………………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:……………………………………….
Supervisor Name	: Dr. ROSZAIDI BIN RAMLAN
Date	: ………………………………………

DEDICATION

To my beloved family and colleagues.

ABSTRACT

Energy harvesting from ambient sources has been a very familiar concept in recent years. In vibration based energy harvesting, resonant linear generators have been the most commonly adopted solution in the harvesting devices. However, several challenges appear when dealing with a linear resonant generator. Among the challenges are the effective power harvested by a linear generator is proportional to the cube of excitation frequency and the power is maximising for a narrow frequency bandwidth only. In this research, ocean wave motion vibration is selected as one of the low frequency sources and its frequency content is investigated. The frequency content is investigated by placing a shock and vibration recorder (MSR) at on-shore, near-shore and offshore at the east coast of Peninsular Malaysia. The measurement shows that the ocean motion vibration is distributed in the low frequency region. Thus, a device that can operate optimally with the low frequency-low amplitude input and has the ability to overcome the narrow frequency bandwidth is invented. Several magnet configurations are suggested to investigate the influences on the stiffness to the proposed design. In one proposed design, the stiffness behaviour of the system is studied by having two single magnets with similar poles (repulsive) and opposite poles (attractive) is placed oppositely. In the second proposed design considered, an oscillating single magnet is placed opposite to the double stationary magnets either attractive or repulsive modes. Another setting is obtained by having an oscillating magnet configured with the repulsive and attractive mode stationary magnets simultaneously. The stiffness of the configurations is related to the degree of non-linearity system. The non-linearity of the system can be adjusted by varying the magnets gap. The non-linear restoring force shows the influences of the linear stiffness and the non-linear stiffness of the system. In this thesis, the analytical solutions to estimate the characteristic behaviour of the magnet configurations are also studied. These proposed designs are then investigated with two main measurements. The quasi-static measurement is conducted to investigate the system stiffness and the dynamic measurement is conducted to investigate the characteristic of the response over a frequency range. It was found that the device is able to increase the frequency as well as amplifying the amplitude of the response. The result also shows that the effective configuration can be made by having the double stationary magnets compared to the single stationary magnet configuration.

ABSTRAK

Penuaian tenaga dari sumber persekitaran telah menjadi konsep yang biasa dalam tahun-tahun kebelakangan ini. Di dalam mod penuaian tenaga melalui getaran, penjana resonan linear adalah penyelesaian yang biasa digunakan dalam alat-alat penuaian. Walaubagaimanapun, beberapa cabaran muncul apabila menggunakan penjana resonan linear ini. Antara cabaran yang dihadapi untuk mendapatkan kuasa berkesan yang dituai oleh penjana resonan linear adalah berkadar dengan kuasa tiga frequensi pengujaan dan kuasa maksimum berlaku hanya dalam lebar jalur frekuensi yang sempit. Dalam kajian ini, getaran hasil dari gerakan ombak laut telah dipilih sebagai salah satu sumber berfrekuensi rendah dan kandungan kekerapannya dikaji. Kandungan kekerapan dikaji dengan meletakkan satu perakam kejutan dan kekerapan (MSR) di persisir pantai, pertengahan laut dan luar pesisir di pantai timur Semenanjung Malaysia. Pengukuran data menunjukkan getaran daripada ombak adalah di dalam jalur frekuensi yang rendah. Oleh itu, sebuah alat yang boleh beroperasi secara optimum dengan input frekuensi-amplitud yang rendah dan mempunyai keupayaan untuk mengatasi jalur lebar frekuensi yang sempit telah dicipta. Beberapa konfigurasi magnet dicadangkan untuk menyiasat pengaruh pada kekukuhan dalam reka bentuk yang dicadangkan. Dalam cadangan yang pertama, tingkah laku kekukuhan system dikaji dengan mempunyai dua magnet tunggal dengan kutub yang sama (menolak) dan kutub yang berlainan (menarik) diletakkan secara bertentangan. Dalam reka bentuk kedua yang dicadangkan, satu magnet yang berayun diletakkan bertentangan dengan dua magnet pegun samada mod menarik atau menolak. Tetapan lain diperoleh dengan meletakkan magnet yang berayun dikongfigurasikan dengan magnet pegun yang bermod menolak dan menarik secara serentak. Kekukuhan konfigurasi adalah berkait dengan tahap bukan linear. Tahap bukan linear boleh diubah dengan menpelbagaikan jarak antara magnet. Tenaga yang tersimpan dalam bukan linear menunjukkan pengaruh daripada sistem kekukuhan linear dan kekukuhan bukan linear. Dalam tesis ini, penyelesaian dalam analisis untuk menganggarkan ciri-ciri perlakuan konfigurasi magnet juga dikaji. Penjana yang dicadangkan ini telah diuji dengan dua pengukuran utama. Pengukuaran kuasi- statik telah dilakukan untuk mengkaji kekukuhan system dan pengukuran dinamik telah dilakukan untuk menyiasat ciri-ciri tindak balas dalam frekuensi. Ini telah mendapati bahawa penjana ini dapat meningkatkan kekarapan dan juga meninggikan amplitud tindak balas. Hasil kajian juga menunjukkan bahawa konfigurasi berkesan dapat dihasilkan dengan mempunyai dua magnet pegun berbanding konfigurasi magnet tunggal.

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α	-	Non-linearity coefficient
α_s	-	Seeback coefficient
$a(t)$	-	Acceleration signal
a_n	-	Fourier coefficient
A	-	Amplitude of the input displacement
b	-	Relative displacement
b_n	-	Fourier coefficient
c	-	Damping coefficient
c_n	-	Magnitude of Fourier coefficient
ζ	-	Damping ratio
d	-	Axial gap
d_l	-	Vertical distance
δ	-	Potential barrier
E	-	Young's Modulus
I	-	Second moment of area
k	-	Spring coefficient
P	-	Power
T	-	Period of the motion
k_c	-	Linear stiffness (cantilever beam)
k_1	-	Linear magnetic stiffness
k_3	-	Non-linear magnetic stiffness

L	-	Length (cantilever beam)
m	-	Mass
n	-	Geometrical parameter
$q_{A,B}$	-	Magnetic moments
r	-	Radius (magnet)
$\Delta Temp$	-	Temperature difference
t	-	Time
τ	-	$\omega_n t$
u	-	Ratio between relative displacement and input displacement
PE	-	Potential energy
$PE_{1,2}$	-	Stable equilibrium position
P_3	-	Unstable equilibrium position
U_h	-	Amplitude of half power point
U_m	-	Maximum relative transmissibility
U_d	-	Amplitude at the jump-down frequency
μ_0	-	Permeability
V_{out}	-	Output voltage
ω	-	Input frequency/fundamental frequency
w	-	Width (magnet)
ω_n	-	Natural frequency
y	-	Deflection (cantilever beam)
Ω	-	Non-dimensional frequency
Ω_m	-	Non-dimension frequency at the peak response
Ω_d	-	Non-dimensional estimate of jump-down frequency
Ω_h	-	Non-dimensional estimate of half power point frequency
φ	-	Phase angle between the response and the input

$\emptyset$	-	Diameter of the magnet
$(\bullet)''$	-	${d^2}/{d\tau^2}$

LIST OF PUBLICATIONS

1. Hilmiah A Ghani, Roszaidi Ramlan, Mohd Juzaila Abd Latif, Low Pei Sing, 2015. Broadening the bandwidth of energy harvesting devices by using different magnet configurations. *Proceeding of Mechanical Engineering Research Day 2015.* pp. 131-132.
2. Hilmiah A Ghani, Roszaidi Ramlan, Mohd Juzaila Abd Latif, Low Pei Sing. Improving the performance of a vibration energy harvesting device using magnets. *ARPN Journal of Engineering and Applied Sciences-(*Accepted)

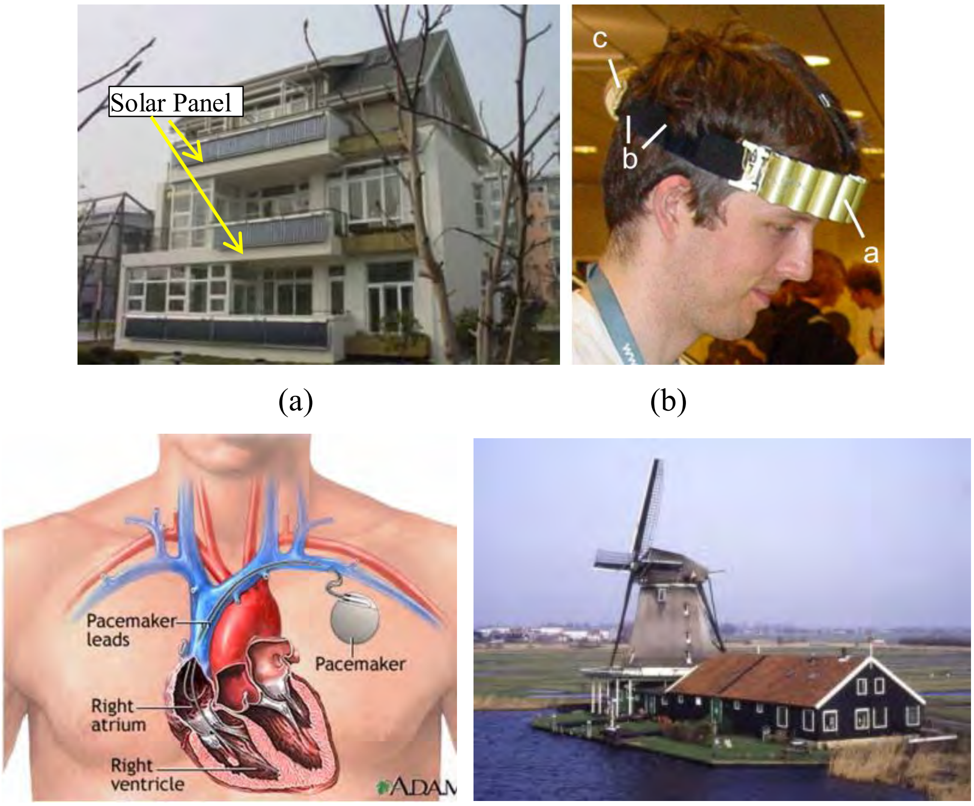
CHAPTER 1

INTRODUCTION

1.1 Background

Advances in technology has made it possible to develop wireless sensor networks (WSN) consisting of small and portable devices. Such WSN is not limited to environment monitoring only but also widely used in the health care monitoring, industrial monitoring, military applications and structural health monitoring. Traditionally, these devices require power source to operate the system. An obvious choice for power source is the battery (Powers, 1995, Roundy et. al., 2004). However, the use of WSN for a long time is constrained by the supply of energy due to limited battery lifetime. Thus, the batteries must be changed or recharged regularly to grant a continuous operation. In many cases, the need to replace batteries would be tough when devices are in hostile environments, remote locations (e.g. pipelines), or even in the case when they are embedded in structures such as pacemaker and cochlear implant. In addition, the process of recharging and replacing the battery increases the maintenance cost. Because of the limitations of batteries, alternative power sources are needed especially for low powered applications with long lifetime requirement. Ambient sources such as solar, thermal, vibration and wind are found to be beneficial for harvesting energy.

Figure 1.1 shows the example of energy harvesting applications from the ambient sources. Figure 1.1(a) shows the installation of solar panels on the sideboards of balconies at the residential building. Here, the solar supplied the power to integrate the energy system for heating, air-conditioning, natural ventilation and hot water for the residents applications (Zhai et. al., 2008). Torfs et. al. (2008) proposed a wireless electroencephalography (EEG) system which fully powered by human body heat using a thermo-electric generator as shown in Figure 1(b). Figure 1(c), on the other hand, shows an ideal self-powered pacemaker which converted the heart beat into electrical energy via electromagnetic induction of the piezoelectric effect (Sue and Tsai, 2012). Figure 1(d) shows the windmill generator which is used to grind seeds to produce vegetable oils.



(a) (b)

(c) (d)

Figure 1.1: The example of applications energy harvesting from the ambient sources; a) Solar source [Source: (Zhai et. al., 2008)], b) Thermal source [Source: (Torfs et. al., 2008)], c) Vibration source [Source: (www.nlm.nih.gov)] and d) Wind source [Source: (Clark, 2014)].