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

2016
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HILMIAH BINTI A.GHANI

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

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016
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

ACKNOWLEDGEMENTS

All praise to Almighty, Allah for the strength and His blessing. First and foremost, I would like to praise and thank Allah S.W.T, who granted the countless blessing and guided me throughout the completion of this Msc degree. I would like to express my deepest thanks to my research supervisors, Dr Roszaidi bin Ramlan and Dr Mohd Juzaila bin Abd. Latif for their motivation, encouragement, immense knowledge, and guidance helped me to understand the research’s world.

Besides that, I would like to express my appreciation and special thanks to the Vibroacoustics team, Centre for Advanced Research on Energy (CARE) and Sustainable Maintenance Engineering (SuSME) groups of Fakulti Kejuruteraan Mekanikal (FKM), UTeM for their great idea, cooperation and advices until this study has been accomplished successfully. My heartfelt thanks to research mate, Ms Low Pei Sing for her sincere help and stimulating discussion during my study. Besides, I would like to express my appreciation to the technical staffs of the Vibroacoustics, specifically Mr. Johardi bin Abdul Jabar and Mr. Azhar bin Ab Aziz for their consistent technical advices.

Special thanks to the financial support from the Ministry of Higher Education Malaysia through the ERGS grant (ERGS/1/2012/TK01/UTeM/02/6-E00006) and MyMaster sponsorship. It may not have been possible for me to carry out this master study at UTeM without the financial assistance from this organization.

Moreover, I express my sincere gratitude to my beloved mother, Pisah@Meryam bt Mohamad and siblings, who provided continuous encouragement, understanding and prayers for me during the hard time. Lastly, millions of thanks to everyone who were involved in this research journey, a journey that made me learned a lot about life.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>DECLARATION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF PUBLICATIONS</td>
<td>xvii</td>
</tr>
</tbody>
</table>

## CHAPTER

### 1. INTRODUCTION

1.1 Background
1.2 Problem statement
1.3 Objectives
1.4 Outline of thesis

### 2. LITERATURE REVIEW

2.1 Energy harvesting
2.2 Ambient sources
   2.2.1 Solar source
   2.2.2 Thermal source
   2.2.3 Vibration source
2.3 Vibration from low frequency
   2.3.1 Harvesting energy from the human movement
   2.3.2 Harvesting energy from the ocean motion
2.4 Limitation of a linear vibration generator
2.5 Strategies to overcome the limitations
   2.5.1 Frequency up conversion method
   2.5.2 Frequency tuning method
   2.5.3 Mechanical stopper method
   2.5.4 Generator array method
   2.5.5 Non-linear method
   2.5.5.1 Mono-stable
   2.5.5.2 Bi-Stable
3. METHODOLOGY 49
  3.1 Introduction 48
  3.2 Measurements of ocean wave motion 50
    3.2.1 Frequency content of the ocean wave motion 52
  3.3 Device design and fabrication 54
  3.4 Theoretical analysis 58
  3.5 Experimental investigation 59
    3.5.1 Quasi-static measurement 60
    3.5.2 Dynamic measurement 62

4. THEORETICAL ANALYSIS 65
  4.1 Static analysis of the restoring force 65
    4.1.1 Forces between magnet 65
    4.1.2 Single oscillating-single stationary magnet (SOSS) 67
    4.1.3 Single oscillating-double stationary magnets (SODS) 74
  4.2 Dynamic modelling analysis 75
    4.2.1 Base excitation 75
    4.2.2 Frequency response curve (FRC) 79
    4.2.3 Jump-down and jump-up phenomenon 82

5. EXPERIMENTAL RESULTS AND DISCUSSION 88
  5.1 Measurement from the ocean wave motion 88
    5.1.1 Reconstruction measurement signal results 93
  5.2 Response from the measurement 95
    5.2.1 Effect of separation gaps 95
      5.2.1.1 Single oscillating-single stationary attractive magnet (SOSS-A) 95
      5.2.1.2 Single oscillating-single stationary repulsive magnet (SOSS-R) 100
      5.2.1.3 Single oscillating-double stationary attractive magnets (SODS-A) 104
      5.2.1.4 Single oscillating-double stationary repulsive magnets (SODS-R) 110
      5.2.1.5 Single oscillating-double stationary mixed (attractive plus repulsive) magnets (SODS-M) 113
    5.2.2 Response for the different level of input displacement 116
    5.2.3 Response for the different configurations with similar gap 118

6. CONCLUSIONS AND FUTURE WORKS 121
  6.1 Conclusions 121
  6.2 Future works 123
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Parameters of the device.</td>
<td>55</td>
</tr>
<tr>
<td>3.2</td>
<td>Classification of the configurations magnets during the experimental investigation.</td>
<td>58</td>
</tr>
<tr>
<td>5.1</td>
<td>The values of the non-linearity predicted using measured quasi-static response.</td>
<td>97</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>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: (<a href="http://www.nlm.nih.gov">www.nlm.nih.gov</a>)] and d) Wind source [Source: (Clark, 2014)].</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>The vibration energy harvesting can be found from the various sources such as, a) Automotive (railcar) [Source: (Ung et. al., 2013)], b) Human movement [Source: (Xie and Cai, 2015)] and c) Structural (bridge) [Sources: (Galchev et. al., 2011) and (Zhong et. al., 2015)].</td>
<td>4</td>
</tr>
<tr>
<td>2.1</td>
<td>Micro power generator, (a) Vibration based generator [Source: (Zhu et. al., 2013)] and (b) Thermal based generator [Source: (Torfs et. al., 2006)].</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>Seiko Thermic wristwatch using the temperature difference provided by body heat and ambient temperature (a) Seiko Thermic wristwatch (SBET001), (b) A cross-sectional diagram, (c) Thermaoelectric modules, and (d) Thermospile array [Source: (Paradiso and Starner, 2005)].</td>
<td>13</td>
</tr>
<tr>
<td>2.3</td>
<td>Increasing number of articles on vibration energy harvesting in engineering village (EI) and web of science (Science Citation Index (SCI)) database [Source: (Zuo and Tang, 2013)].</td>
<td>16</td>
</tr>
<tr>
<td>2.4</td>
<td>Harvesting energy during human walking by a self-powered suspended-load backpack [Source: (Rome et. al., 2005)].</td>
<td>17</td>
</tr>
<tr>
<td>2.5</td>
<td>Harvesting energy during human walking by mounting a geared generator at the knee [Source: (Donelan et. al., 2008)].</td>
<td>18</td>
</tr>
<tr>
<td>2.6</td>
<td>A novel ocean energy permanent magnet linear generator buoy [Source: (Rhinefrank et. al., 2006)].</td>
<td>21</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td>Source</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>2.7</td>
<td>Heaving two stage energy harvester</td>
<td>(Rastegar and Murray, 2009)</td>
</tr>
<tr>
<td>2.8</td>
<td>A linear generator</td>
<td>(Blažauskas et. al., 2015)</td>
</tr>
<tr>
<td>2.9</td>
<td>Microelectromechanical frequency up conversion system</td>
<td>(Sari et al., 2010)</td>
</tr>
<tr>
<td>2.10</td>
<td>a) Frequency up conversion energy harvester and b) Operating principle</td>
<td>(Zorlu et. al., 2011)</td>
</tr>
<tr>
<td>2.11</td>
<td>a) An active frequency tuning device and b) Resonant frequency versus gap</td>
<td>(Zhu et. al., 2008)</td>
</tr>
<tr>
<td></td>
<td>between two magnets</td>
<td></td>
</tr>
<tr>
<td>2.12</td>
<td>a) Resonant frequency method with the use of the attractive magnets and</td>
<td>(Challa et. al., 2008)</td>
</tr>
<tr>
<td></td>
<td>repulsive magnets and b) Experimental result by applying the tuning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>frequency method</td>
<td></td>
</tr>
<tr>
<td>2.13</td>
<td>a) The prototype using a mechanical stopper and b) The numerical and</td>
<td>(Soliman et al., 2008)</td>
</tr>
<tr>
<td></td>
<td>experimental result of frequency response curve</td>
<td></td>
</tr>
<tr>
<td>2.14</td>
<td>a) PZT cantilever with two-side mechanical stoppers, b) Analytical</td>
<td>(Liu et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>simulation on the relative motion of the PZT between one-side stopper and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>two-side stoppers and c) Experimental results for two-side stoppers with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>different top-stopper distance</td>
<td></td>
</tr>
<tr>
<td>2.15</td>
<td>a) The proposed energy harvesting generator consisting various cantilever</td>
<td>(Sari et al., 2007)</td>
</tr>
<tr>
<td></td>
<td>lengths and b) Simulated output power using a series of cantilevers with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>different lengths</td>
<td></td>
</tr>
<tr>
<td>2.16</td>
<td>a) An array of cantilever with five fingers having different width</td>
<td>(Kok et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>and b) Experimental result of the output voltage at the different resistive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>load</td>
<td></td>
</tr>
<tr>
<td>2.17</td>
<td>For-displacement curves characteristic for the non-linear system;</td>
<td>(Nguyen, 2012)</td>
</tr>
<tr>
<td></td>
<td>a) Hardening mode (dashed-dotted), b) Linear (solid) and c) Softening mode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(dashed)</td>
<td></td>
</tr>
<tr>
<td>2.18</td>
<td>Frequency response curve of non-linear system for softening mode, linear</td>
<td>(Nguyen, 2012)</td>
</tr>
<tr>
<td></td>
<td>and hardening mode</td>
<td></td>
</tr>
<tr>
<td>2.19</td>
<td>a) Experiment setup, b) Magnets are model by considering the direction and</td>
<td>(Stanton et al., 2009)</td>
</tr>
<tr>
<td></td>
<td>movement, and c) Frequency response for the different gap</td>
<td></td>
</tr>
</tbody>
</table>
2.20 Comparison between the non-linear softening mode and equivalent linear response for a range of frequency [Source: (Stanton and Mann, 2010)].

2.21 a) The non-linear method using two magnets interaction, b) Frequency response curve for different input level excitation between two repulsive magnets and c) Frequency response curves for different input level excitation between two attractive magnets [Source: (Tang et. al., 2012)].

2.22 a) Schematic of the proposed magnetic levitation device, b) Output power at different amplitude of excitation when the gap between the magnets is 65 mm and c) Output power at different amplitude of excitation when the gap between the magnets is 75 mm [Source: (Gherca and Olaru, 2012)].

2.23 a) Frequency response curve for combining both hardening and softening behaviour and b) Schematic of the proposed device [Source: (Suhaimi et. al., 2014)].

2.24 Force-displacement curve for the non-linear bi-stable mode [Source: (Ramlan et. al., 2012)].

2.25 a) Schematic of arrangement bi-stable energy harvesting device using linear oblique spring \( k_s \), mass \( m \) and damper \( c \) and c) The graph of dimensionless potential energy against displacement [Source: (Ramlan et. al., 2009)].

2.26 a) Schematic a bi-stable system using two repulsive magnets and piezoelectric cantilever beam and b) Potential function against displacement at different gaps [Source: (Ferrari et. al., 2010)].

3.1 The flowchart of the methodology.

3.2 A shock and vibration recorder was mounted on the plate.

3.3 Three axes the shock and vibration recorder.

3.4 The map providing the locations of selected at the east cost of Peninsular Malaysia; a) Pantai Chendering, Terengganu, b) Pulau Kapas, Terengganu and c) Tiong Bravo Platform, Terengganu.

3.5 The proposed energy harvesting device by using the magnetic interaction concept.
3.6 Arrangement of a device.

3.7 a) Single oscillating-single stationary magnet configuration (SOSS). The oscillating magnet and stationary magnet is separated by the gap, \( d \) and b) Single oscillating magnet-double stationary magnets configuration (SODS).

3.8 Attachment of the LVDT and the force gauge during the quasi-static measurement.

3.9 Experimental setup for quasi-static measurement.

3.10 Schematic diagram setup of quasi-static measurement.

3.11 Two Dytran accelerometers were mounted onto the device.

3.12 Experiment setup for dynamic measurement.

3.13 Schematic setup for dynamic measurement.

4.1 The arrangement of the magnets; a) Single oscillating magnet-single stationary (SOSS) magnet and b) Single oscillating magnet-double stationary (SODS) magnets.

4.2 The softening mode of theoretical prediction under different gaps; (a) Force-displacement and (b) Stiffness-displacement curves.

4.3 The bi-stable mode of theoretical prediction under different gaps; (a) Force-displacement and (b) Stiffness-displacement curves.

4.4 The hardening mode of theoretical prediction under different gaps; (a) Force-displacement and (b) Stiffness-displacement curves.

4.5 Base excitation SDOF mass-spring system.

4.6 The frequency response curves for the linear, softening mode and hardening mode.

4.7 Frequency response curve of a hardening mode. Path of sweep-up curve response, \( A-F-B-C-D \) and sweep-down curve response, \( D-E-F-A \).

4.8 Frequency response curve of a softening mode. Path of sweep-up curve response, \( A-G-B-C-E \) and sweep-down curve response, \( E-D-C-F-G-A \).

4.9 Theoretical of FRC for a softening mode.
4.10 Frequency response curves for the hardening mode with constant damping, $\zeta$ and different non-linearity, $\alpha$.

4.11 Frequency response curves for the softening mode with constant damping, $\zeta$ and different non-linearity, $\alpha$.

4.12 Frequency response curves for the hardening mode with constant non-linearity, $\alpha$ and different damping, $\zeta$.

4.13 Frequency response curves for the softening mode with constant non-linearity, $\alpha$ and different damping.

5.1 Measurement results from ocean wave motion at the offshore (Tiong Bravo Platform, Terengganu) in time domain (a, c, e) and frequency domain (b, d, f), respectively; $x$-direction (a, b), $y$-direction (c, d) and $z$-direction (e, f). This measurement was taken on 31st January 2015 (181500).

5.2 Measurement results from ocean wave motion at the near-shore (Pulau Kapas, Kuala Terengganu) in time domain (a, c, e) and frequency domain (b, d, f), respectively; $x$-direction (a, b), $y$-direction (c, d) and $z$-direction (e, f). This measurement was taken on 31st October 2014 (151500).

5.3 Measurement results from ocean wave motion at the on-shore (Pantai Chendering, Kuala Terengganu) in time domain (a, c, e) and frequency domain (b, d, f), respectively; $x$-direction (a, b), $y$-direction (c, d) and $z$-direction (e, f). This measurement was taken on 27th October 2014 (180700).

5.4 Comparison between the time histories for the measured signals (dashed) and the reconstructed signals (solid) (a, c, e) and the Fourier coefficients of reconstructed signals (b, d, f). Signal of the $x$-direction at the offshore (a, b). Signal of the $x$-direction at the near-shore (c, d). Signal of the $z$-direction at the on-shore (e, f).

5.5 a) Fitted force-displacement and b) Stiffness-displacement curves for linear and single oscillating-single stationary attractive magnet configuration (SOSS-A) under different gaps.

5.6 Frequency response curves for linear and single oscillating-single stationary attractive magnet configuration (SOSS-A) under similar input, $A = 0.25$ mm with different gaps; a) Linear, (b) SOSS-A1, (c) SOSS-A3 and d) SOSS-A4.

5.7 (a) Fitted force-displacement, (b) Stiffness-displacement and (c)
Potential energy-displacement curves for single oscillating-single stationary repulsive magnet configuration (SOSS-R) under different gaps.

5.8 Frequency response curves for single oscillating - single stationary repulsive magnet configuration (SOSS-R) under different gap, \(d\).

5.9 Frequency response curve for single oscillating-single stationary repulsive magnet configuration (SOSS-R) with different level of input displacement.

5.10 a) Fitted force-displacement and b) Stiffness-displacement curves for single oscillating-double stationary attractive magnets configuration (SODS-A) under different gaps.

5.11 Frequency response curves for single oscillating-double stationary attractive magnets configuration (SODS-A); a) SODS-A1, b) SODS-A2, c) SODS-A4 and d) SODS-A5.

5.12 a) Fitted force-displacement and b) Stiffness-displacement curves for single oscillating-double stationary repulsive magnets configuration (SODS-R) under different gap \(d\).

5.13 Frequency response curves for single oscillating-double stationary repulsive magnets configuration (SODS-R); a) SODS-R1, b) SODS-R2 and c) SODS-R3.

5.14 a) Fitted force-displacement and b) Stiffness-displacement curves for single oscillating-double stationary mixed magnets configuration (SODS-M) under different gap, \(d\).

5.15 Frequency response curves for single oscillating- double stationary mixed magnets configuration (SODS-M); a) SODS-M1, b) SODS-M2 and c) SODS-M3.

5.16 Frequency response curves for SOSS-A1 and SOSS-A2 systems under different level of input displacement, \(A\): solid \((A = 0.25 \text{ mm})\), and dashed \((A = 0.40 \text{ mm})\).

5.17 Frequency response curves for SODS-A2 and SODS-A3 systems under different level of input displacement, \(A\): solid \((A = 0.25 \text{ mm})\) and dashed \((A = 0.40 \text{ mm})\).

5.18 Frequency response curves for SODS-A2 and SOSS-A1. The gap and the input displacement for both systems are 1.5 mm and 0.25 mm, respectively.
5.19 Frequency response curves for SODS-A2, SODS-R1 and SODS-M1 configuration. The gap and the level of input displacement for all configurations are kept similar at 1.5 mm and 0.25 mm, respectively.

7.1 The proposed design for the stationary magnets.
LIST OF SYMBOL

$\alpha$ - Non-linearity coefficient
$\alpha_s$ - 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
$\zeta$ - Damping ratio
$d$ - Axial gap
$d_t$ - Vertical distance
$\delta$ - 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)

\( \Delta \text{Temp} \) - Temperature difference

\( t \) - Time

\( \tau \) - \( \omega_n t \)

\( \nu \) - 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

\( \mu_0 \) - Permeability

\( V_{\text{out}} \) - Output voltage

\( \omega \) - Input frequency/fundamental frequency

\( w \) - Width (magnet)

\( \omega_n \) - Natural frequency

\( y \) - Deflection (cantilever beam)

\( \Omega \) - Non-dimensional frequency

\( \Omega_m \) - Non-dimensional frequency at the peak response

\( \Omega_d \) - Non-dimensional estimate of jump-down frequency

\( \Omega_h \) - Non-dimensional estimate of half power point frequency

\( \varphi \) - Phase angle between the response and the input
\( \phi \) - Diameter of the magnet

\( (\bullet)' \) - \( d^2/d\tau^2 \)
LIST OF PUBLICATIONS


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.

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)].