OPTIMIZATION OF PIEZOELECTRIC ENERGY HARVESTING SYSTEM

CHOW MAN SANG

THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITY MALAYSIA SABAH
2014

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS

JUDUL: OPTIMIZATION OF PIEZOELECTRIC ENERGY HARVESTING SYSTEM

IJAZAH: DOKTOR FALSAFAH

Saya CHOW MAN SANG , Sesi Penagjian 2007 – 2014 , mengaku membenarkan tesis Doktor Falsafah ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis ini adalah hak milik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (/)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ TIDAK SULIT

Disahkan oleh,

(Tandatagan Penulis)

(Tandatangan Pustakawan)

(Prof. Madya Dr. Jedol Dayou)
Penyelia

Tarikh: 6 January 2014

(Prof. Madya Dr. Willey Liew Yun Hsien)
Penyelia Bersama

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

6 January 2014

Chow Man Sang

PS20068666

CERTIFICATION

NAME : **CHOW MAN SANG**

MATRIC NO. : **PS20068666**

TITLE : **OPTIMIZATION OF PIEZOELECTRIC ENERGY HARVESTING SYSTEM**

DEGREE : **DOCTOR OF PHILOSOPHY (PHYSICS WITH ELECTRONICS)**

VIVA DATE : **4 JUNE 2012**

DECLARED BY

1. **MAIN SUPERVISOR**
   Assoc. Prof. Dr. Jedol Dayou — Signature

2. **CO-SUPERVISOR**
   Assoc. Prof. Dr. Willey Liew Yun Hsien

ACKNOWLEDGEMENTS

My thanks go to all those people who have helped me through my academic years at UMS.

To my supervisor Assoc. Prof. Dr. Jedol Dayou, I would like to express my sincere gratitude to you for taking me on as your PhD student; for your expert guidance, support and persistent encouragement throughout my study period, and for sharing with me your experience and expertise in vibration; I feel that together we have made a successful sortie into the field of energy harvesting. It is a privilege to work under you with your extensive knowledge and genuine concern for all your students. I would like to emphasize that your influence on me was not only in acquiring scientific knowledge but also as a better person.

Comments and suggestions in thesis writing from my co-supervisor Assoc. Prof. Dr. Willey Liew Yun Hsien is greatly acknowledge. Thank you for all the encouragement and your belief that I would eventually finish this thesis.

I would like to express my gratitude to Prof. Dr. Vincent Pang, Assoc. Prof. Dr. Ho Chung Mun, Mr. Chu Soong Tau, members of Board of Governers and staff of Institut Sinaran for your encouragement on my study always and your concern about the progress of my study.

I would also like to thank my friends, Ronald, Nelson, Andrew, Yin Ying, Jackson and Shu Kim, in the Energy, Vibration and Sound Research Group (eVIBS) for helping to make the eVIBS laboratory a nice place to work and study.

I have had many fruitful technical discussions with Mr. Yong (Owner of Genius Electronics Enterprise) and Ah Boo (SKTM Master graduate) during my studies. Thanks for your unreserved sharing the knowledge in electronics and programming, respectively, with me.

I am grateful for the financial support, which has made this work possible, from Ministry of Science and Technology Innovation (MOSTI) under the Postgraduate Scholarship Scheme.

I have reserved special mention for my mother and my younger brother for their constant emotional support and encouragement during the course of my studies. I would like to dedicate this dissertation to my mother for always treating my education with the highest importance and for supporting me and being patient with me through the ups and downs of the life. Without your continued love and support that you have always given me, my PhD study would not have been possible.

Thank you.

Chow Man Sang,
23 February 2012

ABSTRACT

In recent years, piezoelectric generator was chosen as an autonomous solution for powering low power electronic devices because it has the advantages of the simplest setup and flexibility in dimension control as well as the fact that abundant mechanical vibrations are available everywhere. However, the present piezoelectric material generates extremely low power density and this has restricted its use in a wide array of applications. Several optimization techniques, such as DC-DC buck converter, synchronous charge extraction and SSHI techniques, with high conversion efficiency at the intermediate stage were successfully developed. But the results relied on the outcome of piezoelectric power harvested at the initial harvesting stage and the optimization works at this initial stage have seldom been reported so far. The objective of this research work was to develop an efficient piezoelectric power harvesting system to optimize and to further increase its power density output at the initial harvesting stage with the availability of the existing piezoelectric materials. This begins with the selection of the fitting theoretical model for the piezoelectric generator in the form of composite cantilever beam and then validation of the selected model. The work continues with the physical optimization for individual piezoelectric beam and configuration optimization as more than one beam was used. The physical optimization focused the parametric studies on physical properties of the piezoelectric material used. The results showed that the generation of energy can be optimized by increasing the cantilever length, increasing the piezo stress and strain constants as well as lower Young's modulus ratio and higher thickness ratio of the material to its host. The optimization study is then performed on two major configurations which are single active layer and two-active layer. The two-active layer piezoelectric beam further extended to the series and parallel connections. The two-active layer piezoelectric beam in parallel connection gave better performance in terms of harvested energy compared to others. In order to increase these outcomes, a new method is proposed by folding a given piezoelectric material equally and then splitting it for the use of electrical power generation. These reduced-width materials lower the damping effect on the setup but keeping the natural frequency of the system

constant, hence the harvesting system becomes more efficient in scavenging energy from vibration. Experimental results showed good agreement with the theoretical expectations. This method can be incorporated into other optimization technique for better result. Moreover, the bandwidth of the harvesting system increased with small modification of the natural frequency of each split material in the system.

ABSTRAK

PENGOPTIMUMAN SISTEM PENUAIAN TENAGA PIEZOELEKTRIK

Penuaian tenaga elektrik daripada persekitaran untuk tujuan menyediakan kaedah autonomi bagi membekal kuasa kepada alat-alat elektronik berkuasa rendah adalah salah satu topik penyelidikan yang popular di tahun kebelakangan ini. Penjana piezoelektrik adalah salah satu kaedah penuaian yang sesuai kerana ia mudah dibina dan mudah dalam kawalan dimensi serta hakikat bahawa banyak getaran mekanikal yang terdapat di persekitaran. Walau bagaimanapun, bahan piezoelektrik sekarang menghasilkan ketumpatan kuasa yang sangat rendah dan ini telah mengehadkan penggunaan yang luas. Walaupun beberapa teknik pengoptimuman sedia ada seperti DC-DC buck converter, cas pengekstrakan segerak dan teknik SSHI, dengan penukaran yang cekap di peringkat perantaraan telah berjaya dibangunkan, keputusan itu amat bergantung kepada hasil kuasa piezoelektrik dituai pada penuaian awal peringkat dan kerja-kerja pengoptimuman pada peringkat awal ini masih jarang dilaporkan dengan nyata sampai setakat ini. Objektif penyelidikan ini adalah untuk membangunkan teknik pengoptimuman yang cekap dan seturusnya memaksimumkannya ketumpatan kuasa daripada piezoelektrik di peringkat awal penuaian. Ini bermula dengan pemilihan model teori yang sesuai untuk penjana piezoelektrik dalam bentuk rasuk komposit. Model elektrik untuk bahan piezoelektrik berdasarkan persamaan hubungkaitnya telah dibangunkan. Dalam usaha untuk memadankan model teori dalam keadaan dinamik, model mekanikal rasuk komposit di bawah getaran dibincangkan dan digandingkan bersama untuk membentuk satu model dinamik penjana piezoelektrik. Ini diikuti dengan pengoptimuman fizikal untuk setiap rasuk piezoelektrik dan seterusnya pengoptimuman konfigurasi rasuk-rasuk berkenaan. Pengoptimuman fizikal memberi tumpuan terhadap kajian parameter sifat-sifat fizikal bahan-bahan piezoelektrik yang digunakan. Keputusan yang diperolehi menunjukkan bahawa penghasilan tenega boleh dioptimumkan dengan tambahan panjang, pemalar tekanan dan terikan piezo yang besar, nisbah modulus Young yang rendah dan tinggi nisbah ketebalan berbanding bahan substrat. Kajian kemudiannya diteruskan kepada pengoptimuman dua konfigurasi rasuk *piezoelektrik yang utama iaitu satu lapisan aktif dan dua lapisan aktif. Seterusnya, konfigurasi rasuk dua lapisan aktif dikaji iaitu sambungan sesiri dan selari. Didapati bahawa rasuk dua lapisan aktif selari mempunyai kemampuan yang lebih baik berdasarkan tenaga yang dituai bandingan konfigurasi yang lain. Bagi meningkatkan hasil yang optimum ini, satu teknik baru dicadangkan iaitu dengan melipat satu-satu bahan piezoelektrik dengan saiz yang sama, dan kemudian membelah bahan tersebut untuk penjanaan tenaga elektrik. Pengurangan lebar bahan ini menyebabkan penurunan kesan redaman sistem tetapi tidak mengubah frekuensi aslinya. Oleh itu sistem penuaian menjadi lebih cekap dalam menuai tenaga dari getaran. Kaedah ini digunapakai bersama dengan kaedah pengoptimuman yang lain untuk penuaian yang lebih tinggi. Tambahan pula, lebar jalur system penuaian ini dapat ditingkatkan dengan sedikit ubahsuai pada frekuensi asli setiap pecahan dalam sistem ini.*

TABLE OF CONTENTS

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORKS

LIST OF TABLES

LIST OF FIGURES

LIST OF FLOW CHARTS