UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

NONLINEAR ENERGY HARVESTING DEVICE FOR LOW FREQUENCY HUMAN MOTION APPLICATION

Khalis Bin Suhaimi

Master of Science in Mechanical Engineering

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NONLINEAR ENERGY HARVESTING DEVICE FOR LOW FREQUENCY HUMAN MOTION APPLICATION

KHALIS BIN SUHAIMI

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

Faculty of Mechanical Engineering

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DECLARATION

I declare that this thesis entitled "Nonlinear Energy Harvesting Device for Low Frequency Human Motion Application" 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 : KHALIS BIN SUHAIMI

Date :……

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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 RAMLAN

Date : ……

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DEDICATION

To my beloved family and colleagues.

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ABSTRACT

Energy harvesting from ambient sources had received much attention in the past few years due to worldwide awareness on green technology expands. In vibration based energy harvesting, resonant linear generator are commonly used as the harvesting devices. However, a linear generator induces several limitations. The power harvested by a linear generator is proportional to the cube of excitation frequency and the power is maximum in a narrow bandwidth only. In this research, human motion vibration was selected as an input excitation and its frequency content is investigated. The frequency of human motion was investigated by placing a vibration recorder on a test subject under 5km/h walking and 9 km/h jogging speed.The investigation shows that the human motion vibration is distributed in the low frequency region. Hence, a device that can operate optimally with low frequency input and has the ability to overcome the narrow bandwidth limitation is designed. A device is designed to overcome the limitations of the linear generators. This device has the combination of the tuning, frequency-up conversion, multimodal and non-linear techniques. The aim is to amplify the input frequency to a higher frequency and at the same time, widen the bandwidth of response. The frequency-up mechanism is made by transforming the translation motion into the rotary motion by using gear ratio to amplify the response to a higher rotational speed. Winding springs are used with twistable enclosure cap to alter the device stiffness. The angles of twist of the enclosure cap are ranging from 180 degree to 900 degree. Two oscillating masses are connected to the device. Each mass can be set with different characteristic to widen the bandwidth. The two masses are also configured with non-linear softening and non-linear hardening properties to further widen the bandwidth. The non-linearities of the system are changed by varying the magnets gap. The non-linear restoring force of the system shows the influences of the linear coefficient and non-linear coefficient. The device is then investigated with two sets of experiments. The quasi-static measurement is to investigate the system stiffness and dynamic measurement is to investigate its response across a frequency range. In the dynamic measurement the device is excited with sinusoidal inputs and real human motion inputs. Overall, the results obtained from the experiment show that device is able to produce frequency amplification. The response also shows that with a properly tuned system, both softening and hardening can produce a flat response which is insensitive to excitation frequency as well as at amplified amplitude.

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ABSTRAK

Penuaian tenaga daripada sumber ambien semakin mendapat perhatian selaras dengan kesedaran teknologi hijau yang semakin berkembang pesat.Di dalam mod penuaian tenaga melalui getaran, penjana resonan linear adalah contoh peranti yang selalu digunakan. Namun begitu, di dalam mod getaran melalui input dari tapak penjana, penjana linear mempunyai beberapa had ke atas prestasinya. Tenaga yang terhasil oleh penjana linear adalah berkadaran dengan nilai kuasa tiga input getarannya dan tenaga maksimum yang terhasil hanya terdapat di dalam lingkungan frekuensi yang kecil. Di dalam thesis ini, getaran hasil dari pergerakan manusia di pilih sebagai input kepada penjana dan telah dikaji. Kajian yang di buat mendapati bahawa getaran dari pergerakan manusia adalah di dalam jalur frekuensi yang rendah. Maka, penjana yang dapat mengatasi had prestasi penjana linear telah direka. Penjana yang dibinatelah direka bentuk dengan gabungan teknik penalaan, berbilang mod, amplifikasi frekuensi dan kekakuan sistem tidak linear. Teknik amplifikasi frekuensi yang ada pada penjana yang direka telah dilakukan dengan menukar pergerakan selari ke pergerakan putaran oleh gear bernisbah untuk amplifikasikan respon putaran penjana tersebut kepada respon putaran yang lebih tinggi. Spring lingkaran dengan kap yang boleh diubah suai sudut putarannya digunakan untuk mengubah kekakuan sistem penjana.Dua bebanan dengan kebolehan untuk diubah cirinya digunakan pada penjana tersebut untuk melebarkan responjalur frekeunsi penjana.Dua bebanan tersebut telah dikonfigurasi dengan ciri kekauan pelembutan tidak linear dan pengerasan tidak linear untuk melebarkan lagi jalur frekuensi penjana. Kekakuan tidak selari sistem penjana menunjukkan pengaruh pekali linear dan pekali tidak linear kepada kekauan system. Penjana tersebut telah diuji dengan dua set uji kaji iaitu kuasi-statik dan dinamik. Di dalam uji kaji dinamik, dua set input digunakan iaitu input gelombang sine dan input getaran pergerakan manusia. Hasil dari ujian tersebut menunjukkan penjana yang direka dapat menghasilkan amplifikasi frekuensi.Respon penjana yand direka juga menunjukkan, dengan penalaan sistem yang betul, konfigurasi mod sistem perlembutan tidak linear dan pengerasan mampu menghasilkan respon yang mendatar dan tidak sensitive kepada frekuensi pengujaan mahupun amplitude amplifikasi.

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LIST OF SYMBOL

K	-	Thermal Conductivity
S	-	Seeback Coefficient
C	-	Capacitance
Q	-	Charge of plate
Φ_B	-	Magnetic Flux
V_{OC}	-	Maximum Open Circuit Voltage
N	-	Number of Turn in the Coil
B	-	Magnetic Field Strength
H	-	Magnetostrictive Constant
m	-	Mass
$\ddot{x}$	-	Acceleration
$\dot{x}$	-	Velocity
x	-	Displacement
P	-	Power
E	-	Elasticity
L	-	Length
I	-	Moment of Inertia
k	-	Stiffness
R_L	-	Load Resistance
R_c	-	Coil Resistance
ζ	-	Damping Ratio

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ω	-	Input Frequency
ω_n	-	Natural Frequency
k_1	-	Linear Stiffness Coefficient
k_3	-	Non-linear Stiffness Coefficient
a_n	-	Fourier Coefficient
b_n	-	Fourier Coefficient
c_n	-	Magnitude of Fourier Coefficient
θ	-	Angular Displacement
ϕ	-	Pre-stress Angle
C_m	-	Magnetic Permeability
F_m	-	Magnetic Force
Fs	-	Spring Force
F_{muh}	-	Upper Magnet Force Hardening
F_{mlh}	-	Lower Magnet Force Hardening
F_{mls}	-	Lower Magnet Force Softening
F_{Hd}	-	Total Hardening Static Force
F_{Sf}	-	Total Softening Static Force
m	-	Mass
k	-	Spring Coefficient
c	-	Damping Coefficient
y	-	Base Displacement
Y	-	Relative Displacement
α	-	Non-linearity Coefficient
s	-	Relative Displacement

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u	-	Ratio between Relative Displacement and Input Displacement
U_m	-	Maximum Amplitude of the Response
Ω	-	Frequency Ratio
Ω_m	-	Frequency Ratio Where Maximum Response Occurs
d_{uh}	-	Separation Distance between Upper Magnet and Center Magnet (Hardening)
d_{lh}	-	Separation Distance between Lower Magnet and Center Magnet (Hardening)
d_{ls}	-	Separation Distance between Lower Magnet and Center Magnet (Softening)

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CHAPTER 1

INTRODUCTION

1.1 Energy Harvesting

A megawatt power plant produces sufficient electricity to empower house appliances. In house, some appliances or devices use direct plug in socket to operate, however, for the device that uses battery as power source, the socket is merely used to recharge the battery. These kinds of devices can be categorized as wireless or wearable gadgets. In recent years, it has been proven that these kind of gadgets power usage is going towards a smaller scale for its operation, thus it creates an opportunity to create a device that has the ability to harvest energy from ambient sources that can power themselves. The positive side of this is that it can overcome the lack of efficiency that a battery cannot offer but the major task is how to manipulate various sources. Figure 1.1 shows mobile computing improvement and battery energy density over the past few years. The figure indicates that the computing technology improvement increases but the energy density of a battery remain stagnant over the past year.

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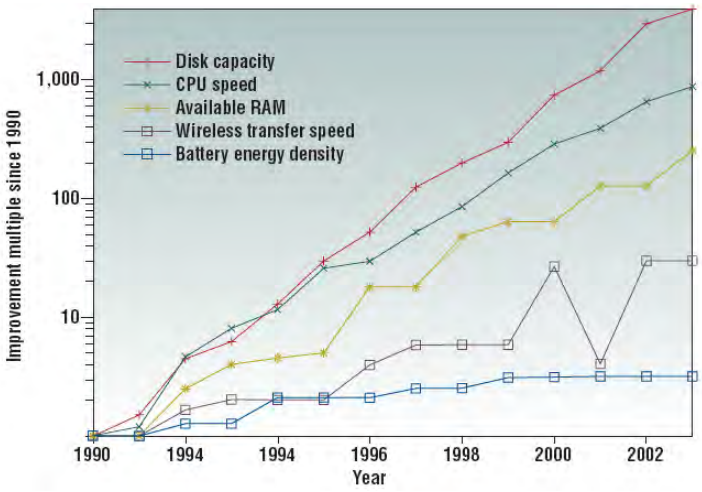

Figure 1.1:Mobile computing improvement and batter energy density improvement [Source: (Cottone, 2011)].

Improvement in the gadget operation means that less power is needed for its operation, which is why most of the gadgets these days are getting smaller. One of the factors is because of the battery size is getting smaller but yet still able to operate the gadgets. Figure 1.2 demonstrates that less power supply is needed due to lower time taken for computation as the technology evolves over the past years.

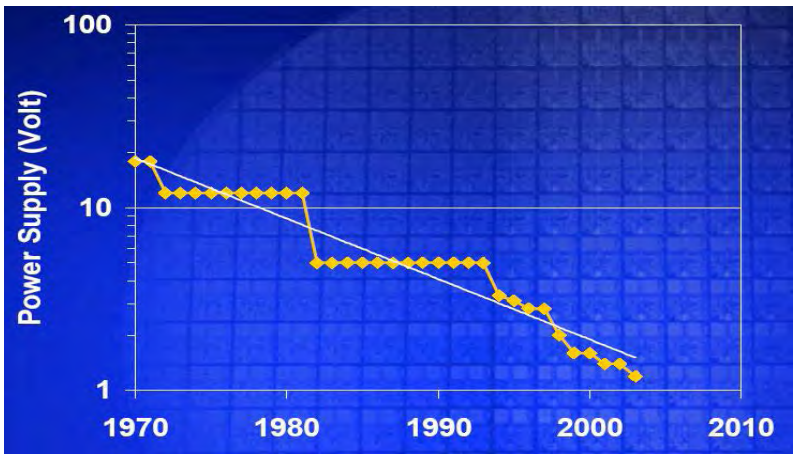

Figure 1.2: The graph of power supply needed for mobile device with respect to the years [Source: (Cottone, 2011)].

Energy harvesting occurs when the available ambient sources are converted into useful energy such as electrical energy. Ambient source such as wind flow, thermal

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