THE PARAMETRIC STUDY OF ELECTROMAGNETIC FOR ENERGY HARVESTER

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Report submitted in partial fulfilment of
The requirements for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

ABSTRACT

Nowadays, the demand of renewable energy is dramatically increased. From the waste of vibration that produced from mechanical system or human being movement, Electromagnetic Energy Harvester (EEH) can generate electricity. EEH is proposed in this thesis which generates electricity from mechanical energy when embedded in a vibration medium. The objectives of the thesis are to analyze the generated voltage and to investigate the performance of the vibration electromagnetic energy harvester for different number of turn coil. A one dimension model was built based on the principle of a spring mass system to convert energy of vibration into electrical energy. It has been designed and fabricated, in which it consists of a permanent magnet Neodymium Iron Boron (NdFeB), a copper coil, a spring and a plastic bottle to turn coil. The minigenerator is made from a coil of wire (about 400-1200 turns) wound around the outside of a plastic 25mm diameter of bottle. The two coil ends are connected to PicosCope software. A magnet is then placed in the bottle with spring where the spring was assembled with the polystyrene base. An EEH was tested by excite the shaker based on the setup of shaker. Because of the resonant frequency, minigenerator generated voltage and directly stores the voltage in the circuit to generate electricity. Analysis predicts that the generated voltage is proportional to the number of turn. As expected, results show that the output voltage increase with increasing number of turns with 74.96033 mV at 100 Hz, 107.6059 mV at 100 Hz and 120.4737 mV at 100 Hz being generated from the 400, 800 and 1200 turn coils respectively. Moreover, to maximize voltage generation, the magnet size and number of turn coil should be as large as possible. Application of EEH is for fabricating Microelectromechanical system (MEMS). MEMS is the integration of mechanical elements, sensor and electronics on a common substrate through the utilization of microfabrication technology (microtechnology).

ABSTRAK

Pada masa kini, keperluan tenaga yang boleh diperbaharui meningkat secara dramatik. Daripada pembaziran getaran yang disebabkan oleh sistem mekanikal atau pergerakan manusia, penuai tenaga elektro atau mini janakuasa (Eelctromagnetic Energy Harvester – EEH) boleh menjana elektrik. EEH dicadangkan di dalam tesis ini di mana ia dapat menjana electrik daripada tenaga mekanikal yang tertanam di dalam medium getaran. Objektif tesis ini adalah untuk menganalisis voltan yang dihasilkan dan untuk mengkaji prestasi getaran elektromagnetik tenaga penuai bagi bilangan lilitan gegelung yang berbeza. Satu dimensi model dibina berdasarkan kepada prinsip sistem jisim dan spring untuk menukarkan tenaga getaran kepada tenaga elektrik. Ia telah direka dan dibina, di mana model ini terdiri daripada magnet kekal Neodymium Iron Boron (*NdFeB*), gegelung tembaga, spring dan botol plastic untuk melilit gegelung. Minijanakuasa tersebut diperbuat daripada satu gelung dawai (kira-kira 400-1200 lilitan) yang dililit pada bahagian luar botol plastik dengan dengan diameter 25mm. Kedua-dua hujung gegelung dawai disambungkan kepada perisian picoScope. Magnet diletakkan di dalam botol di mana ia menyambung dengan spring yang telah dipasang pada tapak polistirena. Shaker akan menghasilkan getaran kepada EEH melalui tetapan sistem shaker. Disebabkan frekuensi resonan, minijanakuasa boleh menjana voltan dan seterusnya menyimpan voltan di dalam litar untuk menjana tenaga elektrik. Analisis meramalkan bahawa voltan yang dijana adalah berkadar terus dengan bilangan gegelung dawai. Sebagaimana yang dijangka, keputusan menunjukkan bahawa keluaran voltan meningkat apabila bilangan gegelung dawai meningkat dengan 74.96033 mV pada 100 Hz, 107.6059 mV pada 100 Hz and 128.6778 mV pada 400 Hz yang dihasilkan masing-masing daripada 400, 800 and 1200 bilangan lilitan. Selain itu, untuk memaksimumkan penjanaan voltan, saiz magnet dan bilangan gegelung mestilah sebesar yang sesuai. Aplikasi EEH adalah untuk fabrikasi sistem Microelectromechanical system (MEMS). MEMS ialah penyepaduan elemen-elemen mekanikal, sensor dan elektronik ke atas substrak yang biasa melalui penggunaan teknologi mikrofabrikasi (microteknologi).

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F	The impact force
A_g	The host structure vibrates with acceleration
F_L	The vertical components of the electromagnetic (Lorentz)
D	The structural damping coefficient
ξ_t	The transducer damping factor
y_0	The amplitude of vibration
ω	The angular frequency of vibration
m	Mass
K	The spring constant
$Z(t)$	The spring deflection
$Y(t)$	The input displacement
N	Turn of coil
P	Generated power
Ø	Wire diameter
δ	Elongation of spring
U	Energy
W	Weight of mass
g	Gravity

LIST OF ABBREVIATIONS

EEH	Electromagnetic Energy Harvester
MEMS	Microelectromechanical system
KE	Kinetic energy
DAQ	Data acquisition system
PC	Personal computer
SIMO	Single-input Multi-output
NdFeB	Neodymium Iron Boron
emf	Electro Motive Force
FEA	finite element analysis

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This thesis proposes to investigate the effect of the different number of coils to electromagnetic energy harvester. This chapter will discuss about the project background, problem statement, project objective and the scope of the project.

Energy harvesting is the process by which ambient energy from the environment is stored to extract an amount of electricity for small application usage. In simple word, energy harvesting is defined as a conversion of ambient energy into usable electrical energy. Various devices have been reported to scavenge energy from different source such as in mechanical vibrations. Besides, energy harvesting is a very attractive technique for a wide variety of self powered Microsystems. A relative simple method for determining the electromechanical parameters of electromagnetic energy harvester are presented in this paper.

1.2 PROJECT BACKGROUND

Energy harvesting devices scavenge energy from the environment such as ambient forced excitation, flow induced vibration, wind power and mechanical itself and electromagnetic harvesting, and is one of the oldest techniques for energy harvesting. Most of the popular studies were focused on a single degree of freedom system and there are lots of possibilities in creating the energy harvester.

The supply of power to such systems has so far been through batteries. However, in long-lived systems where battery replacement is difficult and in applications consisting of completely embedded structures with no physical links to the outside world, generating power from ambient sources become imperative. Systems that depend on batteries have a limited operating life, while systems having their own self-powered supply unit have a potentially much longer life. A potential solution to batteries is the use of miniature renewable power supply unit. Such device convert energy from existing energy sources within their environment into electrical energy. The source of energy is depending on the application. The most familiar ambient energy source is solar power (light energy from ambient light such as sunlight).

This thesis approach uses mechanical vibration as the ambient energy source for generation of electrical power. In this thesis, a vibration based magnet-coil power generator is described. A vibration-electromagnetic energy harvester is developed and the amount of electricity produced is investigated. A device is a kinetic energy generator which derives electrical energy from the vibrations and movements that occur within its environment. The design utilizes an electromagnetic transducer and its operating principle is based on the relative movement of a magnet pole with respect to a coil. The most important parameter influencing the design of such system is conversion efficiency and output voltage. The output voltage and electricity produce is depending on turn of coils. For this study, it will be focused on affect the performance of electromagnetic energy harvester in different number of coils used.

1.3 PROBLEM STATEMENT

Generally in this study, energy harvester is proposed to be built and studied because the demands of renewable energy are dramatically increased. From the waste vibration that produced from mechanical system or human being movement. Amount of electricity can be extracted for small application usage. Actually, to generate electricity energy, transduction method for the generator has three possible transduction mechanisms namely piezoelectric, electromagnetic and electrostatic. In this thesis, a new power supply that generates electricity from mechanical energy by electromagnetic transduction is proposed. This is intended for use in vibrating structures.

In electromagnetic-energy harvesting, a magnetic field converts mechanical energy to electrical. Methods to increase the amount of electricity and to induce voltage include by increasing the number of turns of the coil and increasing the permanent magnetic field. Both of the methods can affect the performance of the energy harvester. In this study, the numbers of turn coil are given more attention due to investigate the effect of performance of electromagnetic energy harvester. The magnitude of this voltage is proportional to the numbers of turn coil.

1.4 PROJECT OBJECTIVE

The objectives of this project are as follow:

a) To fabricate an electromagnetic energy harvester
b) To investigate the performance of the electromagnetic energy harvester for different number of coils.

1.5 SCOPE OF THE PROJECT

The scopes of the project are limited to:

a) Although many types of transducer, this project only extracts the most of electromagnetic type, which is a net movement between the mass and the coil.
b) Measuring the generated voltage by using picoScope software with set up the frequency at 50 to 500 Hz.
c) Electromagnetic energy harvester using a shaker as a device to produce vibration.
d) Investigate the generated voltage from vibration source of shaker in different number of coils regarding to Faraday’s Law concept.

1.6 CHAPTER OUTLINE

This thesis is organized into five chapters. Each chapter will explain stage by stage to complete this project whether in experiment or theoretical. The first chapter will discuss about the project background, problem statement, project objective and the scope of the project.

Chapter 2 will be reviewed some theory about energy harvester in many aspects and the previous study about electromagnetic energy harvester. Analysis of the effects number of coil an electromagnetic energy harvester is also explained in this chapter.

Chapter 3 presented the research methodology, the procedures to complete my project and application tool that have been used in this project.

Chapter 4 views the result of the amount of electricity produced in electromagnetic energy harvester and discussion of the overall result. Analysis about the output power, output voltage, coherence graph and its relation with natural frequencies is also discussed in this chapter.

In final chapter, the thesis project is summarized and some recommendation works are given to improve the project for future.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the background of energy scavenging (energy harvesting), kinetic energy harvesting, types of transduction mechanism; faraday law and the magnetic field are also discussed. All of this is concern with some previous study in electromagnetic energy harvester.

At this time, energy harvesting approaches that transform light, heat and kinetic energy available in the sensor's environment into electrical energy offer the potential of renewable power sources which can be used to directly replace the battery. It devices scavenge energy from the environment such as ambient forced excitation, flow induced vibration, wind power and mechanical itself and electromagnetic harvesting, and is one of the oldest techniques for energy harvesting.

There are lots of methods and studies have been conducted to increase the performance and the amount of electricity to make sure utilization can be improved to others application that more sophisticated. The subject of this paper is a kinetic energy generator which converts mechanical energy in the form of vibrations present in the application environment into electrical energy. Kinetic energy is typically converted into electrical energy using electromagnetic, piezoelectric or electrostatic transduction mechanisms.

2.2 ENERGY HARVESTING (GENERATOR)

Energy is defined as the ability to do work. Example of daily work is anything that involves moving mass like climbing stairs. Types of energy are heat, light, kinetic energy (movement), chemical energy, gravitational energy and electrical energy. In Physics law, energy cannot be created or destroyed. It can only be transformed from one type to another. To generate electricity, another kind of energy to fuel the process is needed.

Energy harvesting also called as energy scavenging or power harvesting where is the process by which energy is derived from external sources. In another word, energy scavenging is described about an exchange of the ambient energy to electrical energy (Torres et al., 2005). Energy scavenging having a various devices has been reported to scavenge energy from different sources, such as light (Raghunathan et al., 2005), thermal energy **(**Lawrence et al., 2002) and vibration energy (Roundy et al., 2009). All of devices are dependent on the particular application. For example, light it can be a significant source of energy but it can highly subjected to the device. Vibration energy is a moderate source, but it also dependent on the particular application. The energy source for energy harvester is present as ambient background and is free.

Extraction of energy from vibration is based on the movement of a spring mounted (mass relative to the supported frame). It can also produce mechanical acceleration that it turn cause the mass component to move and oscillate (kinetic energy). The damping forces literally absorb the kinetic energy of the initial vibration. Because of vibration, we call that as mechanical energy. Mechanical energy can be converted into electrical energy via an electric field (electrostatic), magnetic field (electromagnetic) or strain on a piezoelectric material. Energy harvesting is the process by which ambient energy from environment is captured and stored (Makihara et al., 2006).

Significant research interest has been attracted to the development of energy harvesters because it addresses the energy issue of the recent growth in mobile electronics and several emerging applications including wireless sensor networks

(Paradiso et al., 2005). Most mobile devices and wireless sensor nodes are currently powered by batteries, which need charging or replacement after a period of time. Clearly, there will be measurable benefits in terms of cost if these devices could be self-powered in part by energy harvesters.

The size of the inertial mass, the frequency and amplitude of the driving vibrations, the maximum available mass displacement and the damping are factors harvesting devices are typically implemented as resonant devices to generate the power output (Beeby et al., 2008).

2.3 KINETIC ENERGY

Kinetic energy is a form of energy that represents the energy of motion. An object that has motion whether it is vertical or horizontal motion has kinetic energy. There are many forms of kinetic energy like a vibrational (the energy due to vibrational motion), rotational (the energy due to rotational motion), and translational (the energy due to motion from one location to another). The amount of kinetic energy that an object has depends upon two variables: the mass (m) of the object and the speed (v) of the object. The following equation is used to represent the kinetic energy (KE) of an object.

$$KE = {}^{1}\!/_{2}\, mv^2 \qquad (2.1)$$

Where:
m = mass of the object
v = speed of the object

Energy source can be generated by kinetic energy, both for human and for environmental energy harvesting devices. To obtaining electrical energy from kinetic energy harvesting, we have the different transduction mechanism. (Mateu et al., 2005). In this section briefly explains about the transduction mechanism.

Table 2.1: Classes of energy harvesting device.

Energy Source	Types of energy
Human	Kinetic, Thermal
Environment	Kinetic, Thermal, Radiation

Source: Mateu et al., 2005

2.3.1 Transduction mechanism

The transduction mechanism itself can generate electricity by exploiting the mechanical strain or relative displacement occurring within the system. The principle of kinetic energy based on the displacement of a moving part or the mechanical deformation of some structure inside the energy harvesting device. Both of displacement or deformation can be converted to electrical energy by three methods. This has been referred to as:

> *Kinetic energy harvesting requires a transduction mechanism to generate electrical energy from motion and a mechanical system that couples environmental displacements to the transduction mechanism* (Beeby et al., 2008).

Beeby et al., 2006 and Roundy et al., 2003 was reviewed three basic mechanisms by which vibrations can be converted to electrical energy: electro-magnetic, electrostatic, and piezoelectric. In the first case, the relative motion between a coil and a magnetic field causes a current to flow in the coil. Each transduction mechanism exhibits different damping characteristic. Several micro-energy harvesting sources are explained below subsections: by an electromagnetic transduction (subsection 2.4), by electrostatic transduction (subsection 2.5) and by piezoelectric transduction (subsection 2.6). Table 2.2 gives a qualitative comparison of the merits of each conversion mechanism.

Table 2.2: Comparison of the relative merits of three primary types of converters

Mechanism	Advantages	Disadvantages
Piezoelectric	No voltage source needed Output voltage is 3-8 V	More difficult to integrate in Microsystems
Electrostatic	Easier to integrate in Microsystems	Separate voltage source needed
Electromagnetic	No voltage source needed	Output voltage is 0.1- 0.2 V

Source: Roundy et al., 2003

2.4 ELECTROMAGNETIC TRANSDUCTION

Electromagnetic is a magnet attached to the mass induces a voltage in a coil as is moves**.** An electromagnetic transduction concerned with magnet and electricity. Electromagnetic energy harvesting is defined as a magnetic field converts mechanical energy to electrical energy. A coil attached to the oscillating mass traverses a magnetic field that is established by a stationary magnet. Inducing a voltage from the coil travels through a varying amount of magnetic flux is based on Faraday's law. To increase the induction, the number of turns of the coil, the permanent magnetic field should be increased and use a transformer. These methods are limited by the size of device.

Beeby et al., 2008 pointed out that an electromagnetic induction is the generation of electric current in a conductor located within a magnetic field. The electricity can generate by either the relative movement of the magnet and coil, or because of changes in the magnetic field and the conductor is typically takes form of a coil. The parameter to determine the amount of electricity is depends upon the strength of the magnetic field, the velocity of the relative motion and the number of turns of the coil.

The magnetic induction transducer is based on Faraday’s law. The existence an electric field causes by the variation in magnetic flux, Φm through an electric circuit. When magnet is moving, whose flux is linked with a fixed coil or with a fixed magnet whose flux is linked with a moving coil will realize by a flux variation. The first configuration is preferred to the second one because the electrical wires are fixed. The relevant magnitude is the magnetic flux through a circuit and to obtain an electric field, the size of the coil will deform inversely to the generated energy. Large area coils will perform better than smaller transducers because with large area of coils will produce big transduction, unless a larger time derivative is involved with the small scale generator. (Ching et al., 2000)

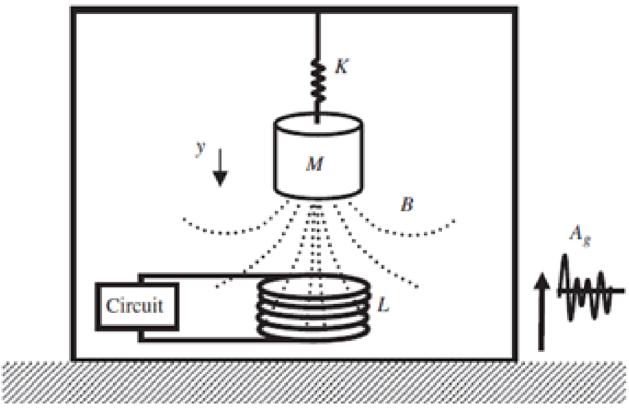

Figure 2.1 A rudimentary electromagnetic energy harvester configuration.

Source: Elvin et al., 2010

This paper briefly presents the analysis of a simple generator. (Ching, 2000). The oscillating mass has a relative displacement with respect to the housing when the generator vibrates. An electrical energy will convert when the magnetic induction generator is relative displacement. A simple electromagnetic generator typically consist of a magnet or mass (m), a suspension spring (k), and an induction coil $(L_c\ )$ attached to an electric circuit. The relative displacement is sinusoidal in amplitude, and can drive transducer to generate electricity. Fig.2.1 shows one simple arrangement with the magnet acting as the mass.

Assuming a masses spring, the one degree of freedom force equilibrium gives

$$M\ddot{y} = D\dot{y} + \ Ky + \ F_L \ = \ -MA_g \qquad (2.2)$$

Where:

The dots represent derivates with respect to time

D = the structural damping coefficient

F_L= the vertical components of the electromagnetic (Lorentz)

A_g= the host structure vibrates with acceleration

2.5 ELECTROSTATIC TRANSDUCTION

Electrostatic is an electric arrangement with a permanent charge embedded in the mass induces a voltage on the plates of a capacitor as it moves. Electrostatic (capacitive) energy harvesting relies on the changing capacitance of vibration depend on the varactors. A varactor (variable capacitor) is initially charged and, as vibrations separate its plates, mechanical energy transforms into electrical energy. Miyazaki et al., 2003 represented that electrostatic generator is a mini generator using a variable-resonating capacitor to convert a mechanical energy to electrical energy. The generator consists of a complete system with a mechanical variable capacitor. Electrostatic transduction exploits the relative movement between two dielectrically isolated electrodes (capacitor). These plates are charged by periodic connection to a voltage source or by the use of electrets. The energy stored in a capacitor, with plate charge Q and potential difference V, is given by:

$$E = 0.5QV = 0.5CV^2 = 0.5Q^2/C \tag{2.3}$$

In case the charge on the plates is held constant the perpendicular force between the plates is given by:

$$F = 0.5Q^2\, d/\varepsilon A \tag{2.4}$$

In case the voltage between the plates is held constant the perpendicular force between the plates is given by:

$$F = 0.5\varepsilon AV^2/D^2 \tag{2.5}$$

The existence of the energy harvester is provided by the work done against the electrostatic force between the plates. In Microelectromechanical system (MEMS) the separation between the two plates is typically very small (nm to μm range).

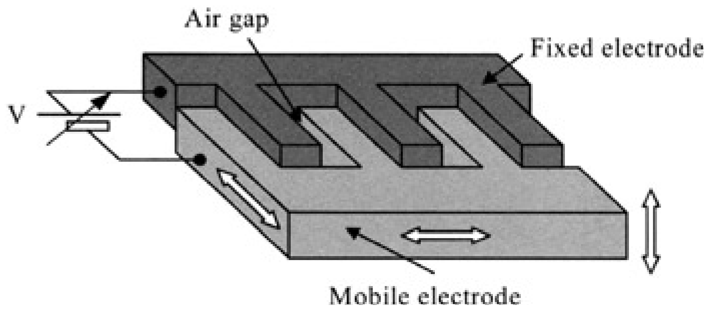

Figure 2.2: Electrostatic generator

Source: http://www.globalspec.com/reference/70614/203279/3-comb-drive-actuator

2.6 PIEZOELECTRIC TRANSDUCTION

Piezoelectric energy harvesting is using piezoelectric material to convert strain (deformation) in the spring into electricity. Strain, or deformation, in a piezoelectric material causes charge separation across the device, producing an electric field and, consequently, a voltage drop proportional to the stress applied. The oscillating system is typically a cantilever-beam structure with a mass at the unattached end of the lever, since it provides higher strain for a given input force. The voltage produced varies with time and strain, effectively producing an irregular ac signal. Electromagnetic system is low of power density and lower velocity compare with piezoelectric conversion energy

Piezoelectric materials are widely available in many forms to loaded energy harvesting applications. In a study by Fanga et al., 2006 noted piezoelectric generators work due to the piezoelectric effect. This is the ability of certain materials to create electrical potential when responding to mechanical changes. Curie's brothers pointed out that certain materials, when subjected to mechanical strain, suffered an electrical polarization that was proportional to the applied strain. This is piezoelectric effect used for mechanical to electrical energy conversion. The existence of an electric field will deform the materials conversely.

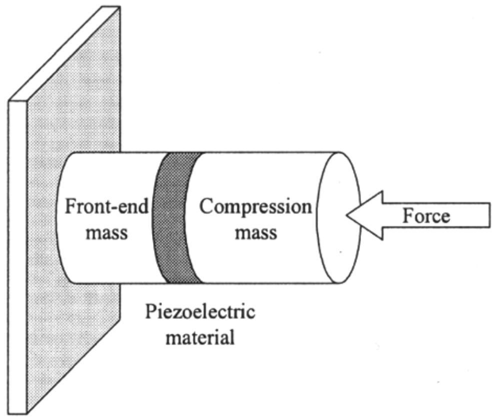

Figure 2.3: Construction of the piezoelectric pulse generator

Source: Keawboonchuay, 2003

(1)

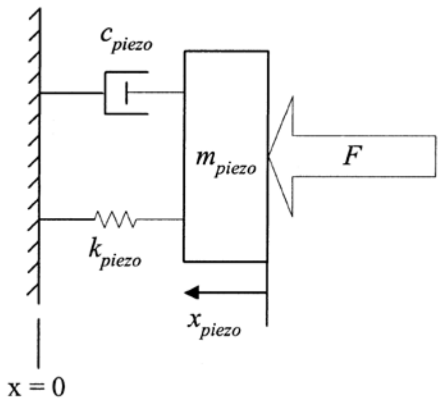

Figure 2.4: Mechanical model of the piezoelectric pulse generator.

Source: Keawboonchuay, 2003

The mechanical model of the piezoelectric generator can be represented with the simple mass-spring system of Fig 2.4. The transient behavior of the mechanical system can be described by the expression. (Rao, 1986)

$$m_{piezo}\,\ddot{x}_{piezo} + c_{piezo}\,\dot{x}_{piezo} + k_{piezo}\,x_{piezo} = F \tag{2.6}$$

Where:

m_{piezo} = the mass of material

c_{piezo} = the damping coefficient

k_{piezo} = the spring constant of material

x_{piezo} = the compression distance of material

$\dot{x}_{piezo}$ =the velocity of material

$\ddot{x}_{piezo}$ = the acceleration of material

F = the impact force

2.7 THE MAGNETIC FIELD AND FARADAY'S LAW

Faraday law is a law that states an electric field is induced in any system in which a magnetic field is changing with time (Rizzoni, 2007). The generated voltage or induced electromotive force, emf (e) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit. In the other word, the emf generated is proportional to the rate of the magnetic flux. The induced voltage represents

$$e = -\frac{d\emptyset}{dt}\ (volt) \tag{2.7}$$

Where:

V @ e = voltage or electromotive force

$\emptyset$ = the magnetic flux (Weber's, Wb)

t = time (sec)

The coil is used to flow the current such a way that the magnetic flux generated by the current would oppose the increasing flux. In practical applications, the size of the voltages induced by the changing magnetic field can be significantly increased if the conducting wire is coiled many times around. So as to multiply the area crossed by the magnetic flux lines many time over. The induced voltage in the coil could be approximated by the following expression: