COMPARISON DIFFERENT TYPE OF MATERIAL FOR 15 SLOT 14 POLE PERMANENT MAGNET LINEAR GENERATOR

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DECLARATION

I declare that this thesis entitled “COMPARISON DIFFERENT TYPE OF MATERIAL FOR 15 SLOT 14 POLE PERMANENT MAGNET LINEAR GENERATOR 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	:	MUHAMMAD FIKRI BIN ROZUKI
Date	:	

APPROVAL

I hereby declare that I have checked this report entitled "Comparison Different Type Of Material For 15 Slot 14 Pole Permanent Magnet Linear Generator" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature	:	....
Supervisor Name	:	....
Date	:	....

DEDICATIONS

To my beloved mother and father

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ABSTRACT

This project about the analysis and comparison the performance of generator at different structure setting under three phase. The project consist of two main component which is permanent magnet as mover made up of NdFeB magnet, SmCo magnet, Alnico magnet and Ceramic magnet by using Halbach array configuration for the setting of direction of magnet that work on the permanent magnet surface and the stator consist 15 slot to place the coil inside. The objective of this project are model and simulate 15 slot 14 pole of permanent magnet linear generator using Ansoft Maxwell software and analyze the permanent magnet linear generator performance with different type of permanent magnet apply on it. In order to achieve the objective, the model of 15 slot 14 pole of PMLG has to construct in Solidwork software. For the simulation result, the model is need to transfer into the Ansoft Maxwell software in 2D to get the analysis result. The speed of the mover moving in 0.5 m / s with the step time 2 ms and stop time 0.1 s in analysis setup of Ansoft Maxwell software. However, the speed of the mover is changed from 0.5 m/s to 1.5 m/s. The focus of this project, to observe the magnetic flux density, flux linkage, cogging force and induce voltage. By the same model, the experiment will be extend by vary the speed mover and the induced voltage is observed.

ABSTRAK

Projek ini mengenai analisis dan perbandingan prestasi penjana pada penetapan struktur yang berbeza di bawah tiga fasa. Projek ini terdiri daripada dua komponen utama iaitu magnet kekal sebagai penggerak terdiri daripada magnet NdFeB, magnet SmCo, magnet Alnico dan magnet seramik dengan menggunakan konfigurasi array Halbach untuk penetapan arah magnet yang berfungsi pada permukaan magnet kekal dan stator terdiri 15 slot untuk meletakkan gegelung di dalamnya. Objektif projek ini adalah model dan mensimulasikan 15 slot 14 kutub penjana linier magnet kekal menggunakan perisian Ansoft Maxwell dan menganalisis prestasi penjana linear magnet kekal dengan jenis magnet yang berlainan yang digunakan di atasnya. Untuk mencapai matlamat, model 15 slot 14 tiang PMLG perlu dibina dalam perisian Solidwork. Untuk hasil simulasi, model ini perlu dipindahkan ke dalam perisian Ansoft Maxwell dalam 2D untuk mendapatkan hasil analisis. Kelajuan penggerak bergerak dalam 0.5 m / s dengan masa langkah 2 ms dan masa berhenti 0.1 s dalam analisis analisis perisian Ansoft Maxwell. Walau bagaimanapun, kelajuan penggerak berubah daripada 0.5 m / s kepada 1.5 m / s. Fokus projek ini, untuk memerhatikan ketumpatan fluks magnet, hubungan fluks, daya cogging dan mendorong voltan. Dengan model yang sama, eksperimen akan diperluas dengan mengubah penggerak kelajuan dan voltan yang diinduksi diperhatikan.

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LIST OF SYMBOLS AND ABBREVIATIONS

WEC	-	Wave energy converter
FEA	-	Finite Element Analysis
PMLG	-	Permanent magnet linear generator
PM	-	Permanent magnet
NdFeB	-	Neodymium iron boron
Alnico	-	Aluminum nickel cobalt
SmCo	-	Samarium cobalt
N	-	Number of turn
H_c	-	Coil height
W_c	-	Coil width
H_m	-	Magnet height
W_m	-	Width magnet
ϕ_c	-	Coil diameter
R	-	Resistor
$\boldsymbol{\theta}_N$	-	Coil sequence

CHAPTER 1

INTRODUCTION

1.1 Project Background

After the '70's oil crisis, many research program were started in that period focusing on renewable energies emerged as a possible long term solution and amongst them the wind and solar energy. Different region has their own way to yield electrical energy based on their renewable source [1]. For region with ocean coasts were focused on ocean energy as their renewable energy. Refer to wave energy converter (WEC), the most recognized are offered in the following traces, along with the operating principle.

Linear generator is considered to have higher efficiency and higher performance in comparison to rotary generator due to the fact they do no longer require any transmission tool [2]. The advantage of the PMLG are better power density, better dynamic overall performance, easy shape and the sensitivity degree of working air gap is small. The gain of fractional slot winding motor is brief quit winding, low copper intake detent force, high energy density and easy to region the winding [3]. Instead of advantage there also some disadvantage represent as a drawback from PMLG such as existence cogging force, excitation is fixed and output voltage varies with load.

In permanent magnet linear generator, there are many type of magnetization array such Radial array, Axial array and Halbach array. Each type of magnetization has their own structure and application. In radial one, magnet display a magnetic area oriented orthogonally to the longitudinal measurement of the device and depending if the device has shifting magnets or transferring armature, they may be positioned internal or outside of the stator. For the axial array, the magnet magnetized separated with the aid of iron core. The flux traces here are directed by way of the iron pole pieces, which are positioned by using two magnets with contrary magnetization direction. Then, the most recommended magnetization configuration which is Halbach array. The magnet configuration can be visible because the superposition of the radial and axial magnetization. A Halbach magnet array is an exciting arrangement of everlasting magnet to increase the magnetic discipline on one facet of the array even as canceling it on the opposite side [4].

This project will analyze and compare the performance of 15 slot 14 pole of PMLG by changing the type of permanent magnet. Linear generator has recently been used in different application, such as wave power conversion. A lot of research is carried out in the field of WEC when wave energy is adequately available and considered to be renewable [5]. This research uses Ansys Maxwell software with the concept of finite element analysis because of the complexity of the model. By using Ansys Maxwell software the results of flux density quantum, induce voltage, flux path, cogging phase and flux density can be reach from the simulation. The PMLG is set to generate Thee phase output power.

1.2 Problem Statement

Generally, the linear generator has higher efficiency and better performance compared to rotary generators, because they do not require any transmission device. Some application which has linear motion mechanism such as wave energy conversion and energy harvesting widely use linear generator. However, a conventional linear generator to rotational generator system has drawback of setting, lubrication, alignment and introduce operation limitation. One encouraging way to convert wave energy into electrical through direct drive is by using a linear, synchronous longitudinal flux permanent magnet generator where the rotor piston is driven by, for example a point absorber. Refer to wave motion, the motion moving up and down linearly.

Among the various type of PMLG, have interesting features those tubular permanent magnet that represent high efficiency, high force density and zero attraction force between stator and mover. The PMLG are classified in longitudinal flux machine and transverse flux machine that depend on the path followed by magnetic flux line. From previous experiment, there are many example of NdFeB magnet linear generator with high cost. So, this research focused if the other material of permanent magnet can have interesting performance. Basically, NdFeB magnet is important for two reasons. First, these alloy produce energy BH 4-5 times higher than older technologies so that give an affect reduce the size and cost. Secondly, these alloys do not contain cobalt, therefore the alloy much cheaper.

The PMLG has advantage in term of efficient electromagnetic performance but has a drawback which is cogging force. At low speed, the machines are much trouble from such ripple that can cause undesirable acoustic noise and vibration. So the speed gives an impact to the performance of PMLG. Thus, the variety of speed effect the performance of PMLG included in this research.

In term of phase, single phase have many problem and issue compare to multiphase. The problem is single phase has no fault tolerance and higher phase rating. For example, multiphase is very useful for Marine current turbine to maintain the power production even if an electrical fault appears in the power converter. The motor of multiphase can be operated normally even though one of phase is in fault condition. So it can be conclude that multiphase winding is better than single phase winding. Hence, this linear generator preferred to design in Three Phase winding.

1.3 Project Objective

1. To model and simulate 15 slot 14 pole of permanent magnet linear generator using Ansys Maxwell software.

2. To analyze the permanent magnet linear generator performance with different material of permanent magnet by varies the speed of mover.

1.4 Scope and Limitation

To achieve the objective of the project, there are several guidelines that have to follow which are improve the modeling of 15 slot 14 pole PMLG using Solid works and the analysis using Ansys Maxwell software and in term of three phase winding. All the parameter including the number of turn, the material of object, magnet sequence and phase angle of coil were identified by using formula that has been calculated and discussed. Then, analyze the performance and result between both. Make a comparison between different types of permanent magnet based on result obtained on 15 slot 14 pole of PMLG respectively, Neodymium Iron Boron magnet

(NdFeB), Aluminum nickel cobalt iron alloys magnet (Alnico), Samarium Cobalt magnet (SmCo) and Ceramic magnet. The range of speed of moving shaft 0.5 m/s until 1.5 m/s with zero current injected in coil winding. The result need to observe such as induced voltage, magnetic flux line, magnetic flux density, flux linkage and cogging force on different mover speed. The best performance of permanent magnet represents highest value of induced voltage proportional to the speed will be selected.

1.5 Thesis Outline

The thesis consists of five chapters: introduction, literature review, methodology, outcome, analysis and discussion, and finally conclusion and recommendation.

Chapter 1 discussed a brief project introduction that includes the statement of problems, objective, scope and limitation. In addition, this chapter describes the general information concerning the permanent magnet.

Chapter 2 will discuss the review of this research's literature. This will include an explanation of the introduction of PMLG and the basic structure of PMLG. The theory of magnetic materials and the slot pole combination of PMLG will also be described in this chapter.

Chapter 3 deals with project methodology. The project activity describes the entire project flow as set out in the project flow chart. The entire method used to carry out this project is explained. The important thing to know is to calculate the sequence of the coil and the number of turns.

Chapter 4 deals with analysis and discussion of results. This chapter will show the overall results of the Ansys software simulation. The discussion of the results for this proposed topic is set out in Chapter 4.

Chapter 5 is the final chapter, which summarizes all the themes of the previous chapter. At the end of this chapter, some recommendations were written for better improvement in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

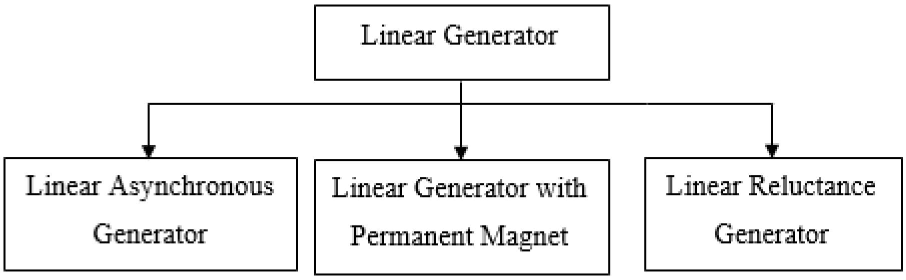
In Chapter 2, all related PMLG theories and literature reviews such as the introduction of PMLG and the basic structure of PMLG are described. This chapter also deals with the magnetic material and the PMLG slot pole combination.

2.2 Introduction Of Linear Generator

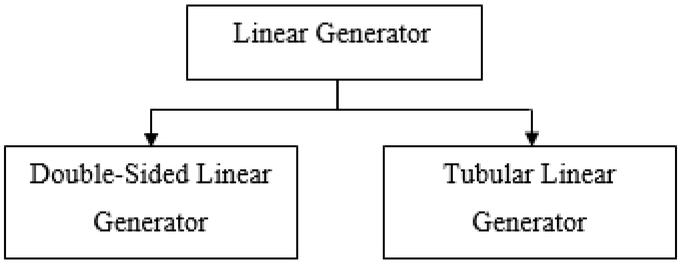
In the evolution structure, the linear generator can be regarded as a rotary generator. It can be seen as a rotor generator in a straight line along the open radial cut and the generator circumference. The stator is a cylindrical dimension with several circular grooves that held the winding of the stator. The moving part of a linear generator which is translator consist of magnetic yokes and permanent magnets. The magnetic yoke is the magnetic path between the magnetic pole. In order to maximize the amount of power at relative low speed, the design concept involving tubular linear generator is the best choice.

The linear generator can be applied and suitable in various type of application and it has been used in industry widely. Linear generator has advantages than any other generator, that are gearbox less, simple structure, high efficiency, high flux density and it could convert energy on the calm wave. However, it still has disadvantages that will give and impact to industry. For example, it has high investment cost, large size dimension for large power generation, has varying voltage and frequency and material required that resist to corrosive materials [6].

There are several types of linear generator that have different in terms of their magnetic and geometric structure [7][8]. In part of magnetic configuration, the linear generator is distinguishing into three types which are linear asynchronous generator, linear generator with permanent magnet that commonly used in many application and linear reluctance. Meanwhile, for the geometric configuration, the linear generator is divided into two types, double-sided linear generator and tubular linear generator. **Figure 2.1** shows the type of linear generator. **Table 2.1** shows the comparison of linear generator with briefly explanation for each criteria such as performance, construction, difficulties, robustness and system cost.



(a) Type of linear generator for magnetic configuration.



(b) Type of linear generator for geometric configuration.

Figure 2.1: The type of linear generator

Table 2.1: Table of comparison for linear generator

Feature	**Linear induction generator**	**Permanent magnet linear generator**	**Switch reluctance linear generator**
Performance	Find little space in the application as wave generator.	-Exhibit high value of residual induction -High BH product allowed to build highly efficient. -Yield high energy density	Constantly changing magnetic field is non-linear, the torque ripple is high at low speed and position sensor complicate the design.
Construction	Manufacture in single-sided, double	Manufactured in single-sided, double	Analogous to the switched

	sided and tubular structure.	sided and tubular structure.	reluctance rotating generator.
Difficulties	-High air gap causing a reduced efficiency. -Complicated control structure.	Present forces perpendicular to the direction of motion that cause mechanical and electrical system complicated.	Complicated control loop and to the magnetization requirement.
Robustness	Rotor made of copper or diamagnetic material cause absence of parasitic force.	Coatings the magnets to slower the oxidation.	High fault tolerance and high reliability.
System cost	Made by sturdy element that have excellent characteristic in longevity.	Short longevity due t to replacement of permanent magnet thus needed for maintenance action.	Linear generator is cheap specially cage generator are maintenance free.

2.3 Basic Principle Of PMLG

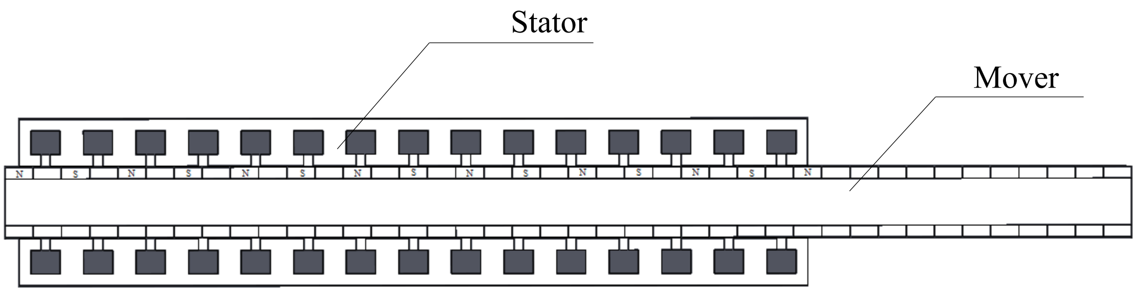


Figure 2.2: Basic principle of PMLG

Figure 2.2 shows the basic principle of PMLG. The PMLG consists of a permanent magnet as the mover and the coil winding stator. The movement of the mover between the stator generates magnetic flux that produces induction voltage on the basis of the law of Faraday. The magnetic flux can be reach higher near the permanent magnet edges, the air gap between stator and translator can be closer to get the value of flux leakage is low.

Faraday’s Law formula:

$$E \quad = \frac{-N\Delta\varphi}{\Delta t} \tag{2.1}$$

$$E = \frac{-N\Delta(BA\cos\theta)}{\Delta t} \tag{2.2}$$

E is induced voltage, N is number of turn, φ is magnetic flux, and θ is angle in degree. The negative sign in Faraday's law is a fact that exist to oppose any change in magnetic flux acted from the induce EMF.

2.4 Basic Structure Of PMLG

The PMLG structure consists essentially of permanent of magnet represent as a mover and the coil is set as a stationary part. It consists of 15 coils in one stator that means 1 coil represent 1 slot, so the total of slot is 15 slots. Meanwhile to determine the pole, it can be identifying by the polarity of magnet from north to south polarity. The number of pole can be evaluate when the polarity of magnet is begin from north to south valued as 1 pole. Each combination of structures is set to winding in three phases. The **figures 2.3** show the different number of pole in PMLG.

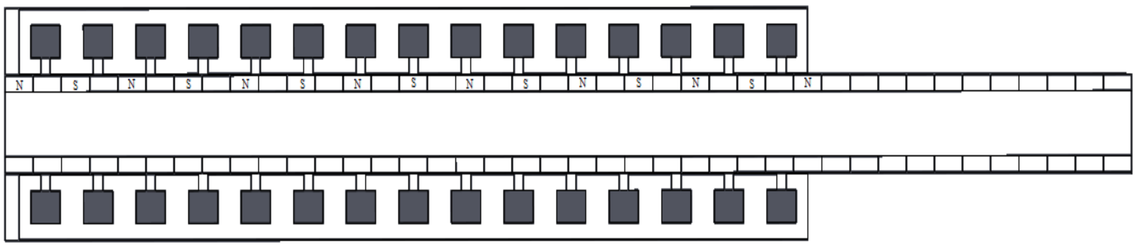


Figure 2.3: Structure of 15 slot 14 pole of PMLG

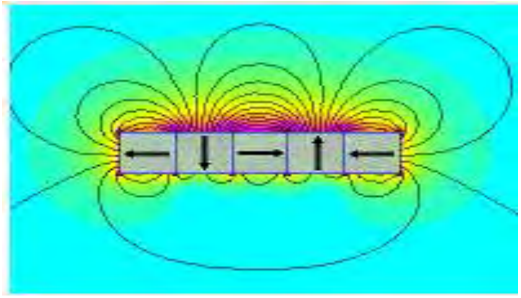


Figure 2.4: Halbach array configuration

Figure 2.4 shows the Halbach array configuration. The linear generator of the Halbach array consists of a permanent magnet in axial and radial direction. It has a much stronger field for a given PM material size and weight than the alternating polarity magnet array. The Halbach array's magnetic field can be concentrated without the use of back iron and the removal of back iron on the stator reduces the overall weight of the generator and eliminates iron-related hysteresis and eddy losses.

A mover magnetic field is generated in the generator either by designing the mover as a PM or by applying a DC current to a mover winding to create an electromagnetic source. The generator mover is then moved by a primary mover, which produces a rotary magnetic field inside the machine. This magnetic field induces a set of three phases of voltages within the coil setting of the generator's stator winding. **Table 2.2** shows the parameter setting which is the most commonly used for setting parameter of PMLG at previous project.

Table 2.2: Parameter setting for PMLG 15 slot 14 pole and 15 slot 16 pole

STRUCTURE PART	PARAMETER	14 POLE	16 POLE
	NUMBER OF COIL	15	15
STATOR	NUMBER OF TURN	158	201
	RESISTANCE	1.81	2.3
	TYPE OF MAGNET	NdFeB	NdFeB
MOVER	SHAFT	SUS304	SUS304
	MAGNET ARRANGEMENT	HALBACH	HALBACH

2.5 Working Principle of PMLG

The dynamic magnetic pole in the direction of the permanent magnet flow is perpendicular to the PMLG axis. The magnetic field line path can be obtained if all the blue magnetic flux is axis direction device, then all red magnetic flux direction is to the axis direction. After the magnetic rotor yokes back to the blue magnetic pole, it forms a loop, the magnetic field line is outwards from the blue magnetic pole through the air gap into the stator core and bypasses the winding through the air gap to the red magnetic pole in the stator core. When the rotor moves a slot to the left, the magnetic field line through the air gap still out of the blue magnetic pole bypasses the winding in the core of the stator through the air gap to the red magnetic pole, when the rotor move continuously. **Figure 2.5** shows magnetic flux direction of the PMLG.

The linear generator has two parts translator and stator. When the translator (mover) moving, the mover induces magnetic flux to stator winding. The coil at stator producing magnetic flux then the mover and stator emf clashed each other and they are produce charged magnetic flux. So, this mechanism is called electromagnetic induction which produce voltage from generator.

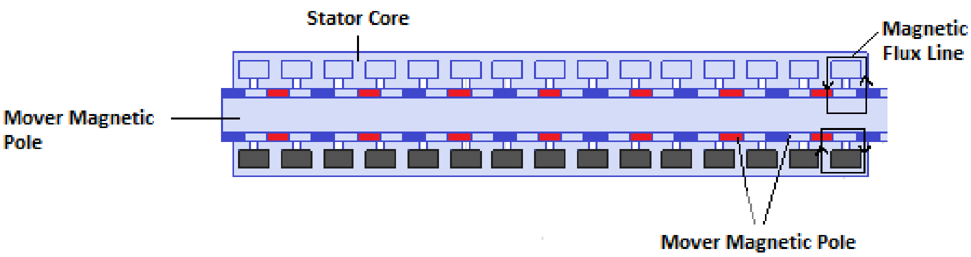


Figure 2.5: Magnetic flux direction of PMLG

2.6 Slot and Pole Combination

The fractional slot concentrated winding PMLG, the slot pole combination, whose pole number increases, the flux linkage decrease due to the leakage flux increment and flux decrement per pole. For the same number of slot, the larger the pole number, the smaller the widths of the inner and outer stator teeth and the slot area become larger when the number of turn per slot is larger. In addition, the larger number of pole give an impact for the iron losses become worse cause by the larger flux densities in the translator.

By using the slot pole combination, whose pole number is greater than its slot number, the thrust and thrust density performance will be reduced, but its detent force and thrust ripple will be much less. **Table 2.3** shows the slot-pole combination [9]. So, this project, we focused on 15 slot 14 pole as a good choice for this project due to high output torque, low torque ripple and low leakage flux.

Table 2.3: Table of slot-pole combination

Number of slot	Number of pole
12	10
	14
15	14
	16
21	20
	22
24	22
	26
27	26
	28

2.7 Magnetic Material

The magnetic material classification based on the magnetic sensitivity of the bulk, which indicates whether the material is attracted or repelled from the magnetic field. The magnetic material performance can be measured on the basis of temperature stability, permeability, coercive strength, resistance to corrosion and mechanical strength. Magnetic material can be classified as ferromagnetic, non-ferromagnetic and permanent magnet in three classes.

2.7.1 Ferromagnetic Material

Ferromagnetic is characterized by its attraction to metals like iron and steel. Ferromagnetic materials may either be soft-ferromagnetic or hard-ferromagnetic