Design and Modelling Linear Motor for Air Conditioning Compressor System

by

Nur Nadia bt Nor Khairul Azha

18250

Dissertation Report submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Electrical & Electronic)

JANUARY 2017

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

32610 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Design and Modelling Linear Motor

for Air Conditioning Compressor System

by

Nur Nadia bt Nor Khairul Azha

18250

A project dissertation submitted to the

Electrical and Electronic Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

Bachelor of Engineering (Hons)

(Electrical & Electronic)

Approved by,

____

(AP Dr. Taib bin Ibrahim)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2017

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

NUR NADIA BINTI NOR KHAIRUL AZHA

ABSTRACT

The increasing in temperature on the surrounding had increased the demand on the air conditioning usage. As air conditioning usage increase, the power consumption on the usage of air conditioning is also increase hence the energy demand increase. In addition, the type of air conditioning system also developed from conventional air conditioning to hybrid inverter air conditioning in order to minimize the usage of power consumption. However, the power consumption of air conditioning still high due to less efficiency of air conditioning compressor system. This phenomenon has driven the search of an alternative way to decrease the power consumption inside the air conditioning. This research main focus on the air conditioning compressor system where many technologies are available for air conditioning however the efficiency of the air conditioning compressor system is low. Thus, a linear motor is designed for this project, the research focuses on the air conditioning linear motor application instead of the current technology which is rotary motor for the air conditioning compressor system. The objective of this project are to design and develop high efficiency of air conditioning compressor system. There are several methodology is implemented in order to finish the research on this project such as conducted literature review, proposed design, obtain preliminary result, and making the comparison throughout the result. By conducting through literature review on the air conditioner and its compressor technology, other configuration of the stator and magnetization, and the structure of the magnet, configuration of this electrical machine is chosen and selected. All of the configuration were implemented on six proposed design which one of them was used a reference as it is the shape of magnet that had been design before. Several aspect is keep constant for this design however the magnet shape is varied. ANSYS Maxwell software is used in order to obtain the preliminary result and analysis also being made from the result obtained. The best result obtained from the preliminary result is chosen. Hence, the cost analysis is estimated for each of the design.

ACKNOWLEDGEMENTS

Praise to Allah SWT for His blessing that I can finish this Final Year Project. Without His Blessing, I may not have opportunity to finish this project.

Secondly, a special appreciation to my university supervisor, Associate Dr Taib Ibrahim for his guidance given throughout this study. He had entertained all my confusion about all things nicely even though my question is very simple.

Next, thanks to EE Department especially: Mr Mohd Zulraimi bin Rahman and Mrs Noralyza binti Mohammed Tamjis for their cooperation and friendly entertained me with the instruments at their laboratory.

Besides, thanks to all the postgraduate members of Associate Professor Dr Taib Ibrahim research group who are Ms. Naily Akmal binti Zamri and Ms. Nur Farahin binti Zulkarnain that acted as my mentor by teaching ANSYS Maxwell software. It is a real pleasure to learn from them. They had set the foundation of the design and analysis work at the laboratory and had been good mentors to me.

Finally, thanks to my beloved parents for their continuous support physically and mentally. They also provided me all the endless support throughout this project to make sure that I can completed my project. Without their support, I may not be able to finish all my studies.

TABLES OF CONTENTS

CERTIFICATION OF APPROVAL ii
CERTIFICATION OF ORIGINALITY iii
ABSTRACT iv
ACKNOWLEDGEMENTS v
CHAPTER 1 1
INTRODUCTION 1
1.0 INTRODUCTION 1
1.1 BACKGROUND OF STUDY 1
1.2 PROBLEM STATEMENT 4
1.3 OBJECTIVES 5
1.4 SCOPE OF STUDY 5
1.5 CONCLUSION 5
CHAPTER 2 6
LITERATURE REVIEW 6
2.1 INTRODUCTION 6
2.2 AIR CONDITIONER TECHNOLOGIES AND ITS WORKING PRINCIPLE 6
2.3 COMPRESSOR AIR CONDITIONER TECHNOLOGIES 11
2.5 TYPES OF LINEAR MOTOR 13
2.6 CONCEPTUAL PROPOSE DESIGN OF LINEAR COMPRESSOR 15
2.6.1 PROPOSED DESIGN 18
2.7 CONCLUSION 21
CHAPTER 3 22
METHODOLOGY/PROJECT WORK 22
2.0 INTRODUCTION 22
PROJECT ACTIVITIES 23
.... 23
.... 23
.... 23
3.2 KEY MILESTONE 24
PROJECT GANTT CHART 26
3.3 CONCLUSION 28
CHAPTER 4 29

RESULT AND DISCUSSION 29
4.0 INTRODUCTION.. 29
4.1 MAGNETIC FLUX LINE DISTRIBUTION AND AIR GAP FLUX DENSITY 29
4.2 MAGNETUDE OF FLUX LINE 36
CHAPTER 5 43
CONCLUSION AND RECOMMENDATION 43
5.0 CONCLUSION.. 43
5.1 RECOMMENDATION FOR FUTUREWORKS.. 43
REFERENCES.. 44

LIST OF TABLES

Table 1 Comparison between linear motor and rotary motor 13
Table 2 Comparison types of linear motor.. 14
Table 3 Average value and maximum value for six proposed designs................................. 36
Table 4 Average value and maximum value for six proposed designs................................. 37
Table 5 Average value and maximum value for six proposed designs................................. 38
Table 6 Average value and maximum value for six proposed designs................................. 39
Table 7 Price and density of each material 40
Table 8 Volume of each linear motor design.. 41
Table 9 Price of each linear motor design.. 42

LIST OF FIGURES

Figure 1 Residential and commercial energy consumption shown as percentage of national energy consumption. [3] 2
Figure 2 Average Daily usage time of respective appliances [2]........ 3
Figure 3 Energy consumption with /without air-conditioner [2] 4
Figure 4 Structure of Air Conditioner [7] 7
Figure 5 Split System Air Conditioning Unit [10]........ 9
Figure 6 Central air conditioners [5]........ 9
Figure 7 Chiller water system [7] 10
Figure 8 Configuration of Linear Motor Tubular/Four Sided Structure 15
Figure 9 Comparison types of stator configuration 16
Figure 10 Rectangular design (Reference)........ 18
Figure 11 Parallelogram design 18
Figure 12 T-Halbach design........ 19
Figure 13 Trapezoid design 19
Figure 14 Triangular design........ 20
Figure 15 T-shaped design........ 20
Figure 16 Structure of Air Project activities and process chart of project 23
Figure 18 Project Gantt chart and Key Milestones for FYP 1 26
Figure 19 Project Gantt chart and Key Milestones for FYP 2........ 27
Figure 20 Rectangular flux line 30
Figure 21 Rectangular air gap density 30
Figure 22 Parallelogram flux line 31
Figure 23 Parallelogram air gap density 31
Figure 24 T-Halbach flux line........ 32
Figure 25 T-Halbach air gap density........ 32
Figure 26 Trapezoid flux line 33
Figure 27 Trapezoid air gap density 33
Figure 28 Triangle flux line 34
Figure 29 Triangle air gap density 34
Figure 30 T-Shape flux line 35
Figure 31 T-Shape air gap density 35
Figure 32 Magnetic flux line and magnetic flux density for each proposed designs........ 35
Figure 33 Flux line vs axial position........ 36
Figure 34 Flux distribution vs axial position 37
Figure 35 Flux linkage vs axial position........ 38
Figure 36 Induced voltage vs axial position 39

CHAPTER 1
INTRODUCTION

1.0 INTRODUCTION

This chapter discusses the distribution of energy consumption in variety sectors. Based on the observation, the conclusion need to be made and residential area are chosen as the main focus in this research due to the inefficient energy towards the residences that result on high bills of electricity. Then, the average appliance usage by the residential area also being taken in order to analyse the main contribution upon the most high power consumption between daily appliances by the residential area. Hence, air conditioning is among the top usage in daily usage that needed very high power consumption is chosen as the research and no further research being done before. Next, the problem statement, objective to this research will be stated, and the scope of study will be further elaborated.

1.1 BACKGROUND OF STUDY

Electricity energy plays main important energy in all aspect in our life. However, the electricity need to be used properly without wasted as there will be more cost to generate the electricity and generated using source like coal and fossil fuel that will caused emission to environment [3]. Therefore, the energy consumption should be well managed

Figure 1shows the residential and commercial energy consumption shown as percentage of national energy consumption. However, focused only at the residential and commercial area even the percentage energy consumption only 15% which is fourth place compare to other sector but it plays important role as it is assume one of the main threat to the consumer as cost of the bills depends on power consumption.

The researchers target for this sector as it is important for energy conservation by reducing inefficient of household energy consumption [3]. Reducing inefficient

energy consumption will reduced the bill cost for the residences [1]. Main focus will be at this sector by further analysis on the contribution of power consumption of household appliances.

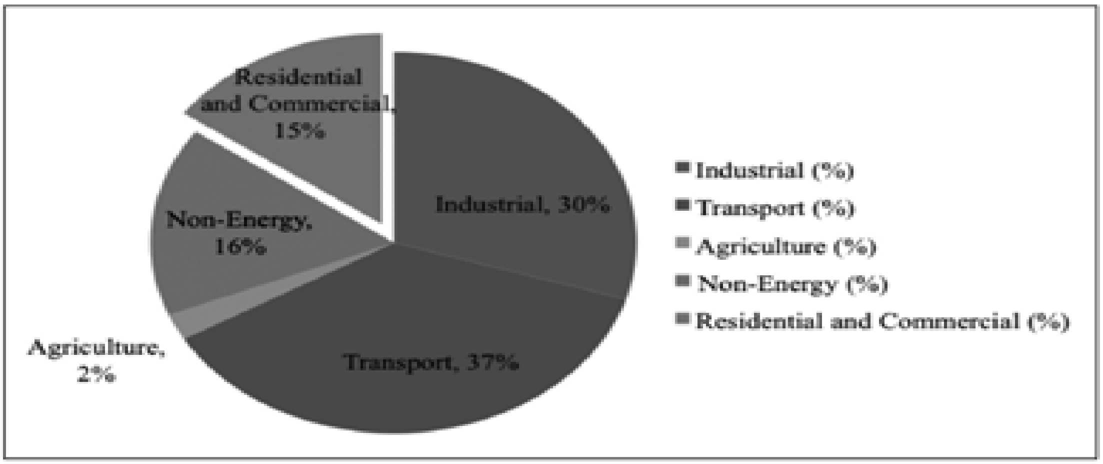

Figure 1 Residential and commercial energy consumption shown as percentage of national energy consumption. [3]

Figure 2 shows the average daily usage time of respective appliances. Among the average, the top ranked with high power consumption is refrigerator and air conditioner. Even though refrigerator ranked the first place of the average usage, it is not chosen due to less power consumption than air conditioner which is 500 watts and 1200 watts respectively [1]. Air conditioner also contributed the largest amount of yearly electricity which are 1167 kWh/year [2].Plus, the research on the refrigerator had been done by previous researcher. Therefore, research had been made to study on air conditioner compressor system of electricity as it contribute high power consumption.

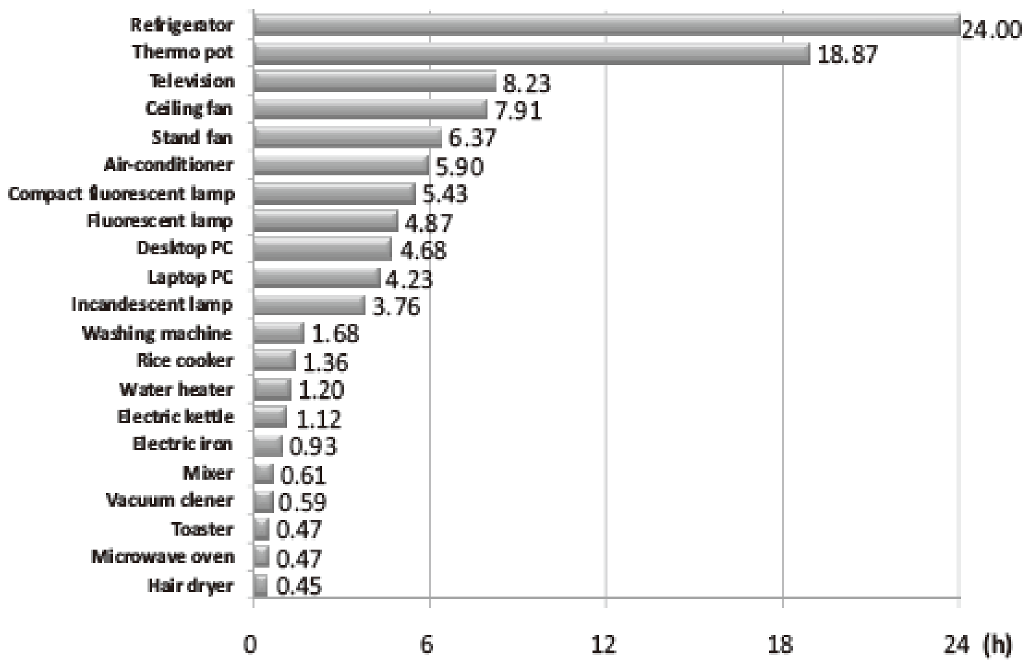

Figure 2 Average Daily usage time of respective appliances [2]

Figure 3 shows energy consumption with air conditioner shows higher energy consumption compare without air conditioner usage. Most of the electricity charged bill will be high if the house consists of air conditioning compare to household without air conditioner [1]. Air conditioner cost is quite expensive due to high power consumption. As air conditioner becoming high demand nowadays, hence it is chosen to be improvised. This is due to increasing climate temperature, the demanding on air conditioning become necessity to society. Hence, it can be the main threat to the environment that will caused the global warming due to increase of carbon dioxide [3].

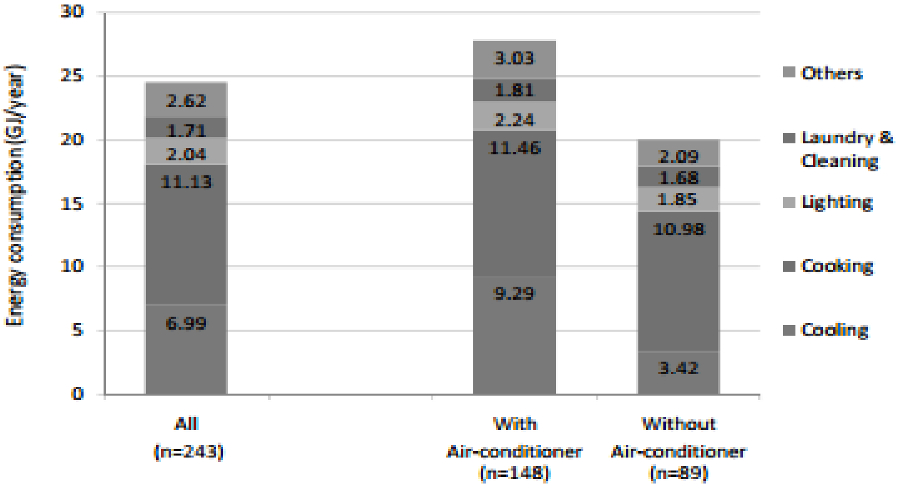

Figure 3 Energy consumption with /without air-conditioner [2]

After many consideration being analyse, air conditioner is chosen as the appliance that can be improvised in order to reduce high portion of the inefficient energy conservation. Besides, it also can reduce the threat to the environment as there is reduce in usage of the electricity as the efficiency of it increasing.

1.2 PROBLEM STATEMENT

Current technology used rotary compressor inside the air conditioning compressor system is less efficient. Rotary compressor electrical machine has less efficiency as compare to reciprocating compressor because it has low pressure due to high volume of the construction. It results on less efficient to pump the refrigerant to whole subsystem. Hence, high power consumption is need in order to make sure the air conditioning working. By improving the air conditioning compressor system, the efficiency of the compressor can be increased, power consumption can be decrease, and reducing the effect to environment as no waste of power generated

1.3 OBJECTIVES

The objective of the study is

- To design the electrical machine of air conditioning compressor system for better efficiency.
- To conduct literature review on various technologies of electrical machines which are suitable for air conditioner system.
- To propose high efficiency electrical machine design that is suitable for compressor usage in air conditioning

1.4 SCOPE OF STUDY

The study will focus on over view of air conditioning technologies and its working principle, types of compressor in air conditioning and making literature review of comparison between rotary motor and linear motor. It will limited to electrical machine design in air conditioner compressor and the proposed design will be simulated using Finite Element Analysis.

1.5 CONCLUSION

Residential sector is found out to be focused on this research as it affected most of society financial. Among the daily appliances used, air conditioner is the most suitable appliances to be focused in order to reduce power consumption compare with other appliances. Power consumption of air conditioner can be concluded is very high. This is due to the air conditioning compressor system that are currently used is less efficient. Rotary compressor electrical machine inside the compressor has less efficiency as compare to linear motor as it has low pressure due to high volume of the construction. Hence, it results on less efficient to pump the refrigerant to whole subsystem. Therefore, the compressor are redesign into linear motor in order to obtain high efficient air conditioner compressor system. In the next chapter, further elaboration on this project will discussed in more details.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Chapter 2 reviews the literature of the past researches on air conditioner technologies such as room air conditioner, central air conditioner, split-system central air conditioner and package central air conditioner and chiller water system. Most of residential used all these type of air conditioners except for chiller water system that widely used for industrial [4]. However, most of air conditioner at residential area apply rotary compressor due to it sizing and functionality is specific for these air conditioner. Comparison had been made between rotary compressor and reciprocating compressor. However, rotary compressor is found out less efficient compare to reciprocating compressor. Therefore, rotary compressor rotary motor is chosen to be converted into linear motor as it result on less efficient of compressor. Therefore, the review focused on the design criteria and specification for rotary motor for air conditioning compressor system. The design will be introduced for further analysis.

2.2 AIR CONDITIONER TECHNOLOGIES AND ITS WORKING PRINCIPLE

The air conditioner technology can be classified based on its room capacity and the working principle. The choice of room capacity for the air conditioner are in small room, large area such as house or industrial places. Different types of air conditioner also have different type of compressor [4]. There are various type of air conditioner depending on the size of the area such as room air conditioner, central air conditioner, split-system central air conditioner and package central air conditioner and chiller water system. Implementation of operating system in air conditioners is the same principle as refrigerator [5].

Most of air conditioners has the same basic working principle which is evaporator coil function to cool up the closed environment. The condenser consist coils release the heat outside. The evaporator and condenser coils that surrounded by aluminium consist of tubing circuit that made up of copper and fins force refrigerant [4]. The compressor used to pump the heated refrigerant throughout the system between evaporator to condenser. As the refrigerant evaporated in the evaporator coil, the indoor environment getting cool. Then, inside the evaporator coil, the refrigerant will be evaporated in the indoor evaporator coil, hence heat is release from indoor air and home is cooling using the blower. The heated refrigerant gas is pumped outdoor into the condenser will reverse back into liquid get rid its heat to the flowing of condenser. However, their structure, type of compressor used and certain functionality make it different [6].

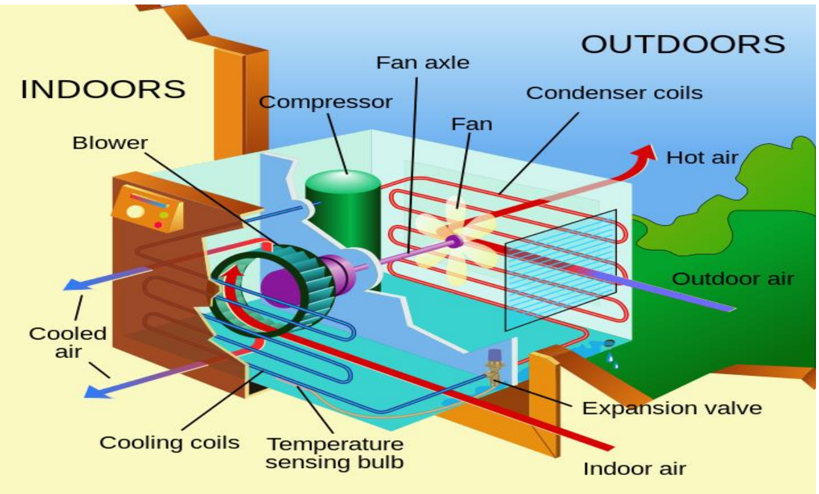

Figure 4 Structure of Air Conditioner [7]

Room air conditioners cool rooms rather than the entire home. If they provide cooling only where they're needed, room air conditioners are less expensive to operate than central units, even though their efficiency is generally lower than that of central air conditioners [4]. Conventional air conditioner, portable air conditioner and window air conditioner can be categorized as room air conditioners.

Conventional air-conditioning has part ventilation system includes two sections which is outdoor units and indoor unit. The open air unit, puts outside the room, houses fragments like the compressor, condenser and extension valve [5]. The indoor unit incorporates the evaporator or cooling loop and the cooling fan. The open air unit interfaces with the indoor unit by two refrigerant tubes. [7].

Next, central air conditioners circulate cool air through a system of supply and return ducts. Supply ducts and registers like openings in the walls, floors, or ceilings covered by grills carry cooled air from the air conditioner to the home [4]. This cooled air becomes warmer as it circulates through the home then it flows back to the central air conditioner through return ducts and registers. A central air conditioner is either a split-system unit or a packaged unit [5].

A split system is a combination of an indoor air handling unit and an outdoor condensing unit. The indoor air handling unit contains a supply air fan and an air-to-refrigerant heat exchanger (or cooling coil), and the expansion device. The outdoor condensing unit consists of a compressor and a condenser coil [4]. Split-systems are typically found in residential or small commercial buildings. Split-system central air conditioner, an outdoor metal cabinet contains the condenser and compressor, and an indoor cabinet contains the evaporator. In many split-system air conditioners, this indoor cabinet also contains a furnace or the indoor part of a heat pump. The air conditioner's evaporator coil is installed in the cabinet or main supply duct of this furnace or heat pump. If your home already has a furnace but no air conditioner, a split-system is the most economical central air conditioner to install [8].

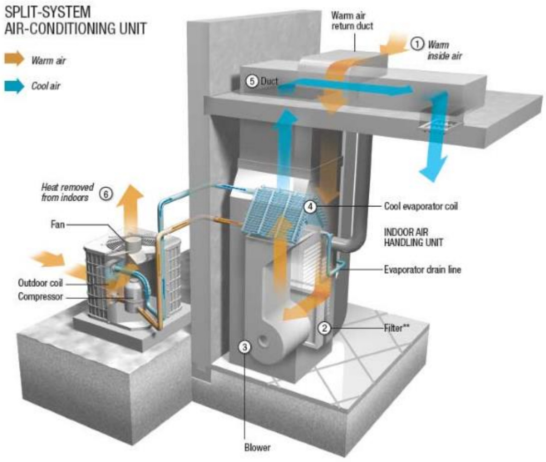

Figure 5 Split System Air Conditioning Unit [10]

In a packaged central air conditioner, the evaporator, condenser, and compressor are all located in one cabinet, which usually is placed on a roof or on a concrete slab next to the house's foundation [4]. This type of air conditioner also is used in small commercial buildings. Air supply and return ducts come from indoors through the home's exterior wall or roof to connect with the packaged air conditioner, which is usually located outdoors. Packaged air conditioners often include electric heating coils or a natural gas furnace. This combination of air conditioner and central heater eliminates the need for a separate furnace indoors [5].

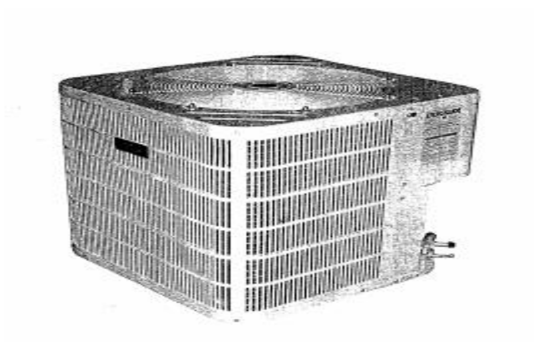

Figure 6 Central air conditioners [5]

In a chilled water system, computer room air conditioning systems is place to the system called water chiller as shown in Figure 7. It function to generate chilled water that will flow through pipe from the chiller to computer room air handlers located in the IT environment. There are certain same between computer room air handlers are similar to computer room air conditioners in appearance but different functionality. It produce cool air by removing through computer room that consist of chilled water coils that consist of circulating chilled water. After the heat get rid from IT environment, the returning chilled water flow back to the computer room. Condenser will receive heat get rid from the returning chilled water for transport to outside atmosphere. Many computer room air handlers apply chilled water systems to cool the entire buildings.

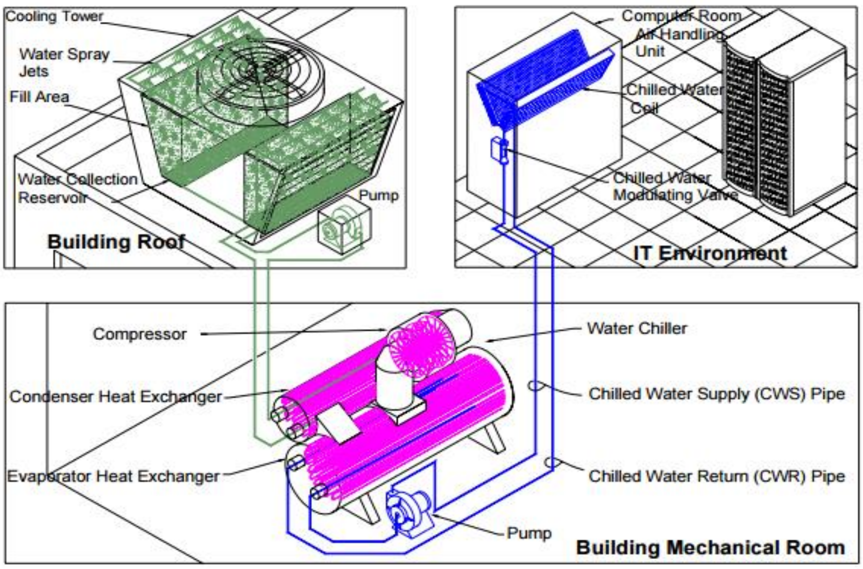

Figure 7 Chiller water system [7]

2.3 COMPRESSOR AIR CONDITIONER TECHNOLOGIES

However, compressor as the main part of vapour compression refrigeration system. It functions as flow the refrigerant through the system and recycles it by eliminate the vapour from evaporator, compresses and warm up the refrigerant vapour and discharge the vapour to condenser. For method of compression, there are divided into two which is reciprocating (linear motion) compressors and rotary compressor [7]. Reciprocating compressor consists of open type, hermetically sealed type and semi-hermetically sealed type while rotary compressor divided into three which is roller type compressors, centrifugal compressors and screw compressors. Most of large area of air conditioner apply reciprocating compressor while most of room air conditioner used rotary as it need low pressure to pump the refrigerant [8].

The advantage of centrifugal compressor compare to reciprocating is more efficiency, less floor area, high speed and operation have no noise while the disadvantages are high volume of refrigerants needed and less pressure increase every stage. Rotary compressor divided into three which is roller type compressors, centrifugal compressors and screw compressors. It works when the evaporator of vapour refrigerant compressed by movement of blade. It has high volumetric efficiency as clearance of it is negligible and it is positive displacement which is collect volume of air and compressed it [8]. Most of reciprocating compressor used in larged area such as central However, reciprocating compressor is more efficient compared with rotary compressor. Hence, rotary compressor is used to be invented for air conditioning instead of reciprocating compressor [7].

There are certain improvised for rotary compressor is utilized as a part of inverter ventilating. It apply ac to dc because of A/C units are very inefficient amid start-up and fluctuate as more a unit cycles on and off, the more energy it wastes. Therefore, get rid the conventional on-and-off cycling, an inverter driven rotary unit keeps an amazing amount of energy as its long cycle-run time. The frequency vary to control and maintain the constant speed of power in compressor so that it can reduced power consumption and control fan motors speed, and varies the voltage to control torque [7].

The hybrid inverter integrates two particular compressor control modules to make sure consistent natural comfort which is obtain with maximum energy efficiency. PAM (Pulse Amplitude Modulation) gives the highest levels of power for when close system need to get cool (or warm) fast, while PWM (Pulse Width Modulation) guarantee the desired room temperature and ideal energy efficiency that is fundamentally less consumption. Hybrid inverted can advantage in energy saving by giving accurate control and cost efficiency with the DC Inverter compressor and ecologically sustainable compressor results in efficient use of power. Next, it is for comfort as DC Hybrid Inverter apply a Twin Rotary compressor, which guarantee a steadier rotation resulting reducing the unwanted vibration sound. Lastly, high power PAM drives high power to ensure the fast accomplishment of the desired temperature. Throughout all the development from conventional to inverter and hybrid, compressor plays an important part in order to increase the efficiency of air conditioning. Therefore, this project will focus on integrate the design of motor in compressor to increase its efficiency to pump the refrigerant [9].

2.4 TYPE OF ELECTRICAL MACHINES

There are two types of machine that can be used in this research which are rotary and linear motor. Conventionally, rotary motor are the most commonly used but there are some drawback such as difficult construction as it involve more mechanical parts. Thus, linear motor is chosen to be design for this research as it has more pros. For instance, the difficult of construction of linear motor are reduced because minimum mechanical part is needed, compared to the rotary motor, hence the reduction of the production cost too. Moreover, the cost of maintenance can also be minimized. For linear motor, it uses the concept of moving in only one direction either horizontally or vertically along x- and y-axes

TABLE 1 tabulates the comparison between linear and rotary motor. It shows that linear motor is more suitable for air conditioner application due to its simple and robust structure. The linear machine can lasts long and cost of maintenance required is low. This will be a big advantage because it will reduce the maintenance cost.

Table 1 Comparison between linear motor and rotary motor

Linear Motor	**Rotary Motor**
Simple structure and robust	Complex structure
Long lifetime	Shorter lifetime
Rotation of translator is vertical	Rotation is on fixed axis
Cannot be connected directly to grid	Can be connect directly to grid
Low maintenance	High maintenance
No mechanical interface required	Hydraulic system or turbine is required

2.5 TYPES OF LINEAR MOTOR

There are types of linear motor that can be used for air conditioning compressor system. The most frequently used is the permanent magnet motor, followed by induction generator, synchronous motor, and DC motor []. All types of linear motor has their own advantages and disadvantages, as summarized in TABLE 2.

Table 2 Comparison types of linear motor

Linear motor type	Advantages	Disadvantages
Permanent Magnet motor	No electricity required for magnetization Suitable for low load application High power and flux density A maintain excitation and harvest a high magnetic flux, thus provides a high efficiency in the range of nominal speed[10]	Expensive magnet installation Weight increases with size High cogging torque[10]
Induction motor	Simple structure Rotor robust construction High-speed operation due to its rotor robust construction[11]	Poor starting torque High starting current Less efficient High power consumption[11]
Synchronous motor	High efficiency at low speed Adjustable power factor Can operate at any speed[14]	Need collector rings and brushes Zero starting torque Need external source for excitation[14]
DC motor	High starting torque Rapid acceleration and deceleration Cheap and suitable for heavy job[16]	Regular maintenance needed Require load before startup[16]

TABLE 2 shows that amongst other, the advantage of permanent magnet motor is that it does not require electricity for magnetization. As for air conditioner compressor system application, it is not suitable for any connection as its will be place inside the air conditioner, therefore, it is not suitable for the compressor application. Therefore the most suitable generator type for this research is the permanent magnet generator.

2.6 CONCEPTUAL PROPOSE DESIGN OF LINEAR COMPRESSOR

There are two main parts that contribute to the compressor performance, which are stator and rotor. The main topology for stator and rotor are listed and will be discussed further below.

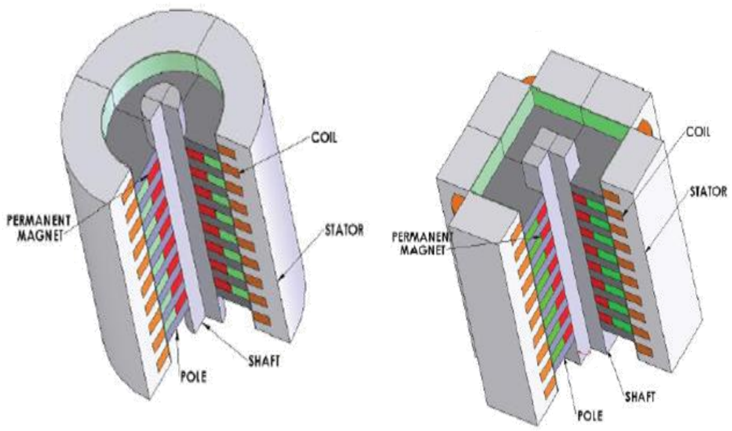

Figure 8 Configuration of Linear Motor Tubular/Four Sided Structure

The aspects such as power density, magnetic flux density, power loss and efficiency needed in order to choose the design. Tubular had been chosen as it consist that needed for the design. It has the highest power density and magnetic flux density is also maintained through the air gap compared to four sided configuration that contributed not consistent magnetic flux density at component of the permanent magnet. Due to number of coil less, the losses such as copper loss is minimum while four sided topology is high. As Tubular topology is in closed loop and the concentrated flux line, it results on better efficiency. Hence, tubular is chosen for the design due to the advantages it can contribute. Therefore, the performance of the motor can be improve [12].

The slotless stator had been chosen instead of slotted stator. There are a few factors is counted in order to choose the stator part such as power density, air gap and many more. However, slotted stator are not chosen due to the cogging at the magnet border that can lead to the damaged of air gap even though it has high density for power. It also results to inconsistent output for the linear compressor [13]. However, cogging is less for the slotless stator hence low potential for magnet to damaged due to the smooth movement even though it may reduce the flux density and induced electromotive force [14].

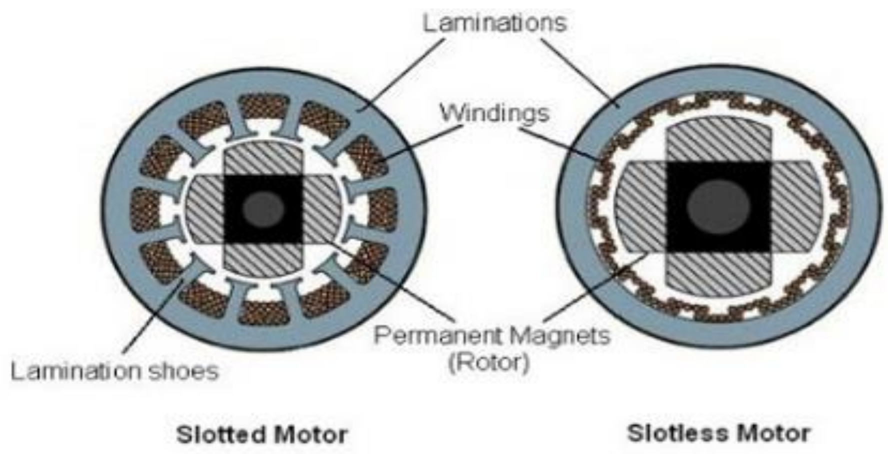

Figure 9 Comparison types of stator configuration

Iron cored is selected as it can produce higher voltage hence higher power output compare to air-cored as it has high flux density in iron core. Hence iron cored is applied for the design. Besides, iron core stator as be good conductor for magnetic flux compared to the air cored. The Halbach type of permanent magnet as it can produced high torque compared to axial and radial[15]. It can produced more torque compared to axial or radial configuration only. Hence halbach configuration is chosen compare to other configuration as it can maximize the result.

The ferromagnetic plate, in a single primary system, is usually placed on the other side of the conducting plate to provide a path of low reluctance to the main flux. The ferromagnetic plate however gets attracted towards the primary when the field is energized. Consequently unequal gap length results on the two sides of the plate. Double primary system can be used to overcome this problem [15].

Finally, for the design, the permanent magnet will be using six different type of magnet and compare the efficiency of rectangular, parallelogram, thalbach, trapezoid, triangular, and tshape. Different magnet shape will produce different output of induced voltage. Rectangular is chosen as the reference as it is the magnet type available in current technology.

2.6.1 PROPOSED DESIGN

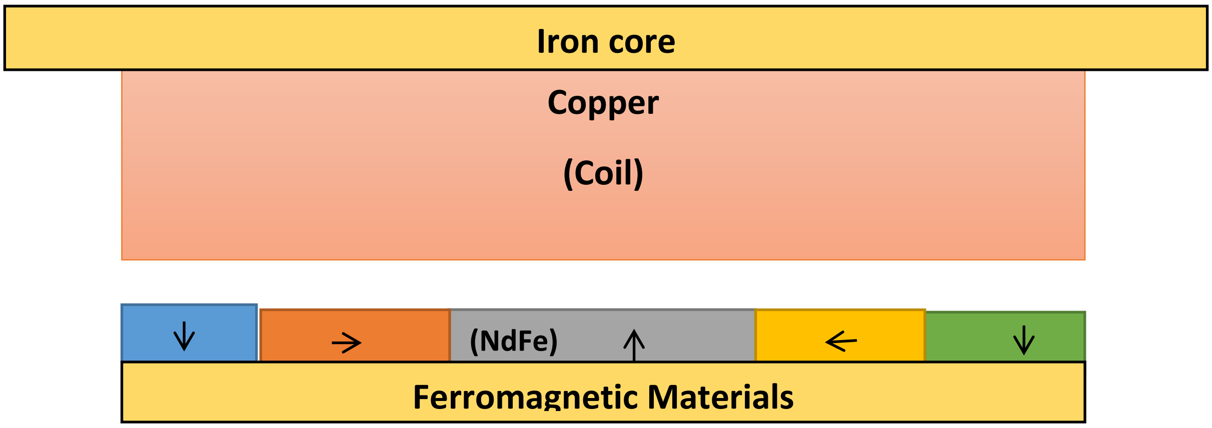

Figure 10 Rectangular design (Reference)

Figure 10 shows the advantages is it has wide area for a magnet which is result large back electromotive force (back-EMF) and force density. The disadvantages of rectangular magnetic are lowest magnetic flux density on zero displacement.

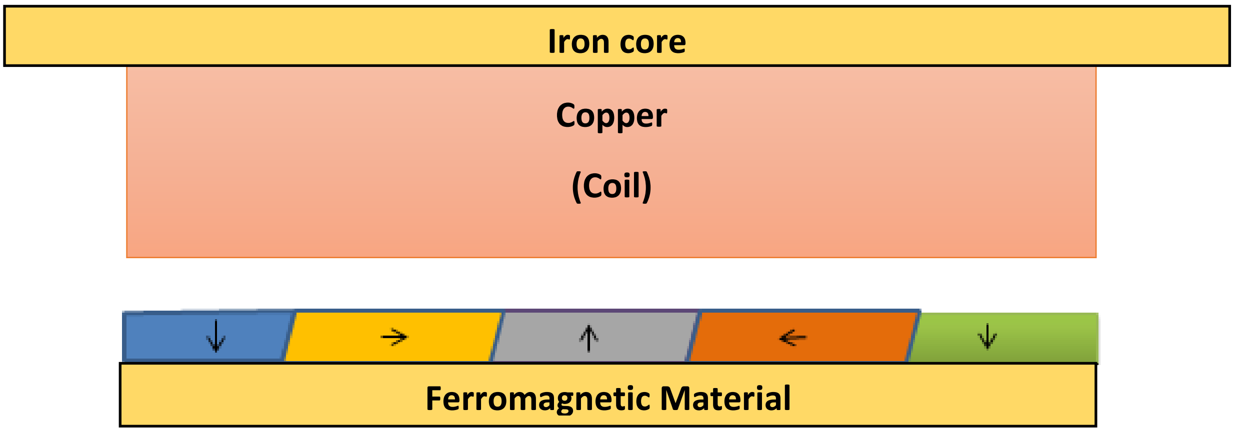

Figure 11 Parallelogram design

Figure 11 show the advantages of parallelogram are quite high magnetic flux density on zero displacement compared to other magnet except triangular layout magnet. It also has second highest characteristics for magnetic flux density and induced EMF. Same also for the efficiency, this shape produce second highest efficiency.

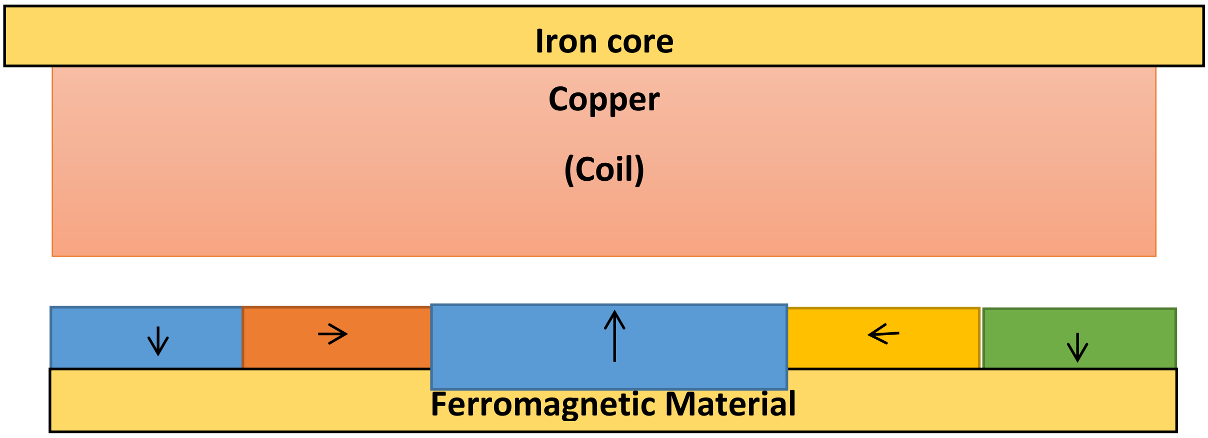

Figure 12 T-Halbach design

Figure 12 shows the advantage of t-halbach is it can produce strong magnetic fields on one side hile making a little stray field on the inverse side. This impact is best comprehended by observed the magnetic flux distribution. It produces the arrays using the ferromagnetic material cobalt to harvest strong magnetic fields for focusing and steering the particle accelerator beams.

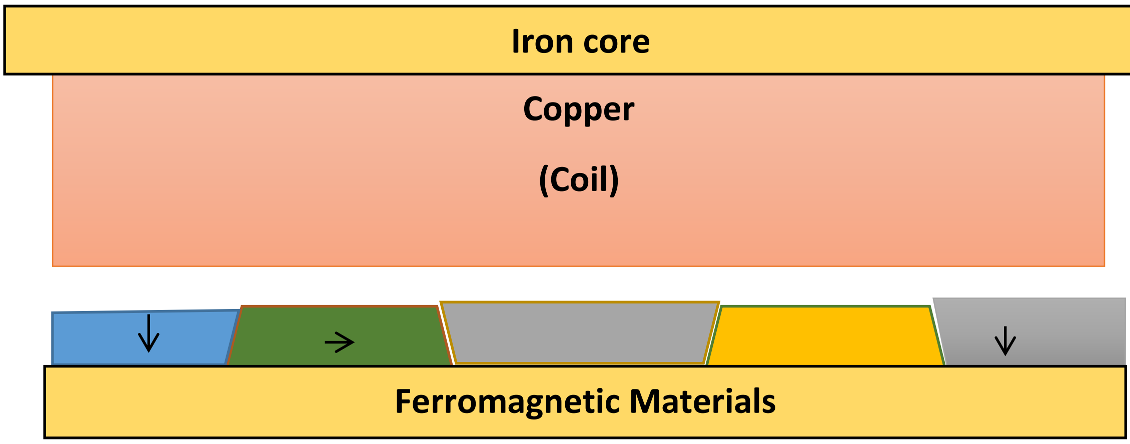

Figure 13 Trapezoid design

Trapezoid design as shown in Figure 13 has bigger size of the radial magnet configuration to increase the density of magnetic flux. The surface area of axial magnet exposed to air gap is smaller compared to the surface at the radial magnet configuration. The shortcoming of this design low efficiency due to lower density of magnetic flux.

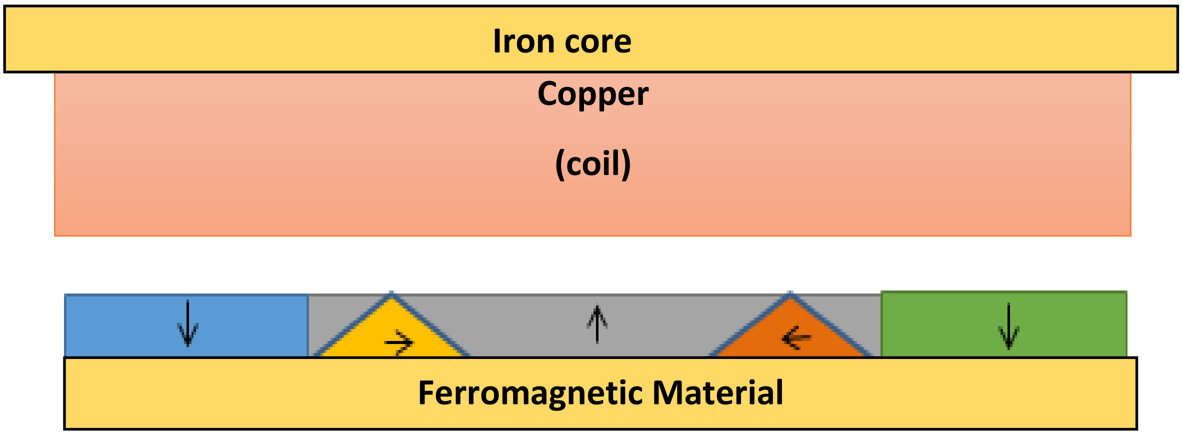

Figure 14 Triangular design

Figure 14 shows triangle design. The advantage of this design is the exposed area to the the air gap at radial magnet configuration is high. This make the magnetic flux density also high. However, the construction of the design will be difficult due to the shape of the magnet has many edges.

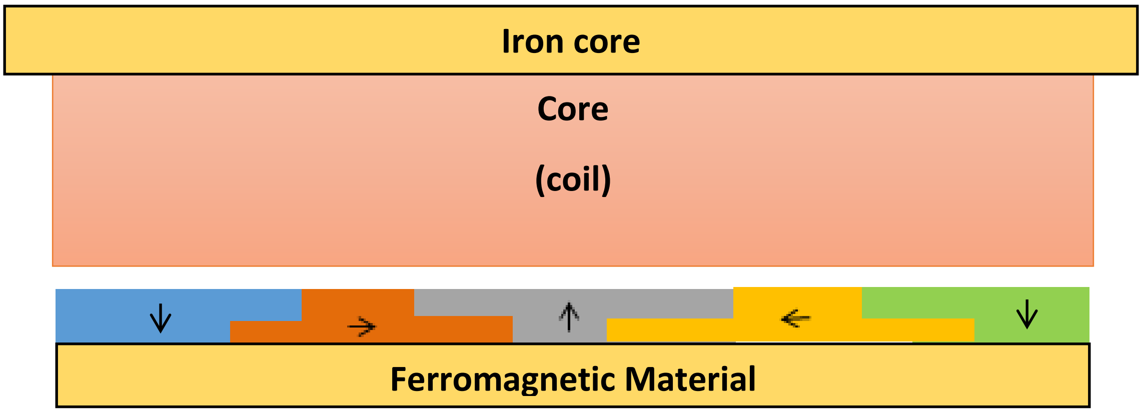

Figure 15 T-shaped design

Figure 15 shows the advantages of t-shape is surface area of the radial and axial the rectangular magnet array design, in terms of flux linkage, Back EMF and cogging force. Subsequently, the analysis of motor performance reveals that the flux density increases with the increase of magnet width. magnetic flux density (B) at air gap of the designs also increase. The disadvantage is t-shape is it has low amplitudes of air gap flux density of motor and difficult construction of its configuration.

2.7 CONCLUSION

Based on the literature review, between the reciprocating compressor and rotary compressor, rotary compressor shows less efficient to air conditioner compressor system. Hence, the most suitable technology need to be improve in order to increase efficiency for air conditioner compressor system is rotary motor. The specification of the motor like the permanent magnet is chosen as it does not required electricity for magnetization. Plus, the type of the proposed design such as tubular shape, slotless magnet, the magnet materials such as iron cored and ferromagnetic magnet are chosen for this research. The Thalbach configuration is selected as it can produce high magnetic flux. Six design are proposed in order to select the best configuration.

CHAPTER 3

METHODOLOGY/PROJECT WORK

2.0 INTRODUCTION

The first step of methodology is literature review. It is the most important part which is researcher need to make sure the journal chosen is the latest journal. Then, the information must be precise and related with background of air conditioning and other thing related to the project such as comparison between linear motor and rotary motor for compressor that can apply in air conditioning. All the information obtains from the journal need to be paraphrase and make sure it is arrange with the right flow so that it is easy to be understood. Next, the information obtain from literature review is used as guideline to design the linear motor for air conditioning compressor. Several specifications can be done for the linear motor by referring to the previous result and come out with efficient linear motor by determine the length of iron core, number of coil, length of permanent magnet and type of ferromagnetic materials.Then, after determine the specification of the linear motor that can fit in the compressor of air conditioner, the simulation process is taking place by using Finite Element Analysis (FEA). Throughout this simulation, the proposed design in term of the flux line, flux density, air gap flux distribution and open circuit test is obtain. The result can be used to determine the best design of linear motor. Finally, comparison needs to be done in order to strong the design and make some chance that can increase efficiency and decrease drawback designation of linear motor. Figure 4 is the step process of the project and figure 5 is the list activities of the project.

PROJECT ACTIVITIES

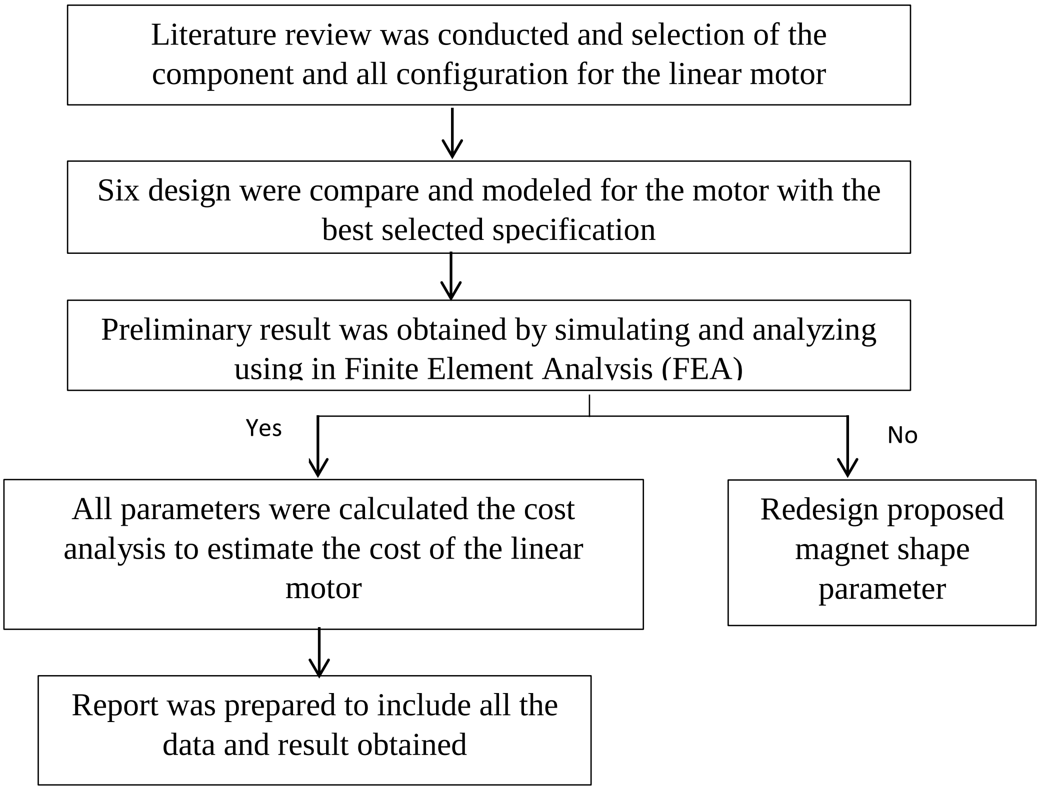

Figure 16 Structure of Air Project activities and process chart of project

3.2 KEY MILESTONE

1. Literature review

The literature review in this thesis mainly focused on the comparison between each proposed design and modelling for air conditioning compressor system based on their performance and efficiency usage of the power supply. First, the literature review explains about the definition and development of air conditioning system through several past year. It is then continued by explaining the difference between linear compressor and rotary compressor. Lastly, the literature review discussed about the types of linear motor and each of the proposed design with addition with the diagram.

2. Propose design for the linear motor

The six designs were proposed and compared for their best selected specification to meet the requirements needed. The six designs are namely convectional layout, rectangular, thalbach, trapezoid, parallelogram, triangular, and t-shaped. Each of the design discussed specifically to point out each of their own advantages and disadvantages that suit with the requirements needed.

3. Simulation and Analysis

The results of the research are obtained through finite element analysis (FEA). Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. By using Finite element analysis, the propose designs can be simulated and analysed through it flux density, air gap flux density and back EMF.

4. Cost Analysis

The cost for the design is calculated based on the density and volume of the materials.

5. Compare the performance of the generator

After all the result and data have been gathered, the report is then been done which includes all the details and information about the research and discussed project. Related references also been provided which been used in the research and also gives extra information to the readers and researchers such as flux line, air gap density, flux linkage and induced voltage.

6. TOOLS

Several tools will be implemented to obtain data collection, simulation of type of magnets and their efficiency such as the flux density, air gap flux density and back emf.

7. ANSYSMAXWELL

ANSYSMAXWELL shall be used to simulate the six type of magnet shape. This software is choose as the simulation platform due to it is easy to be used and the output to analyse it can be obtain an their efficiency can be analy

PROJECT GANTT CHART

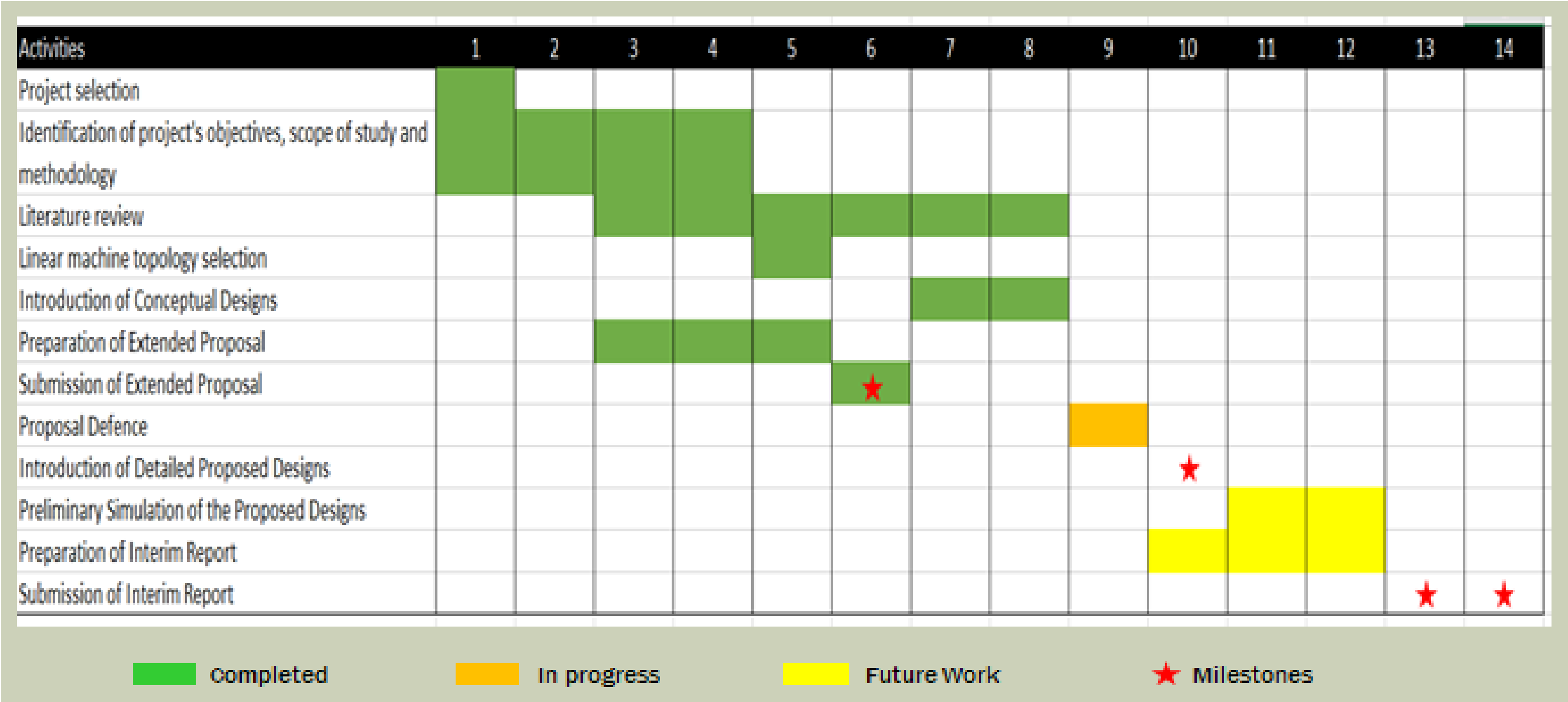

Figure 17 Project Gantt chart and Key Milestones for FYP 1

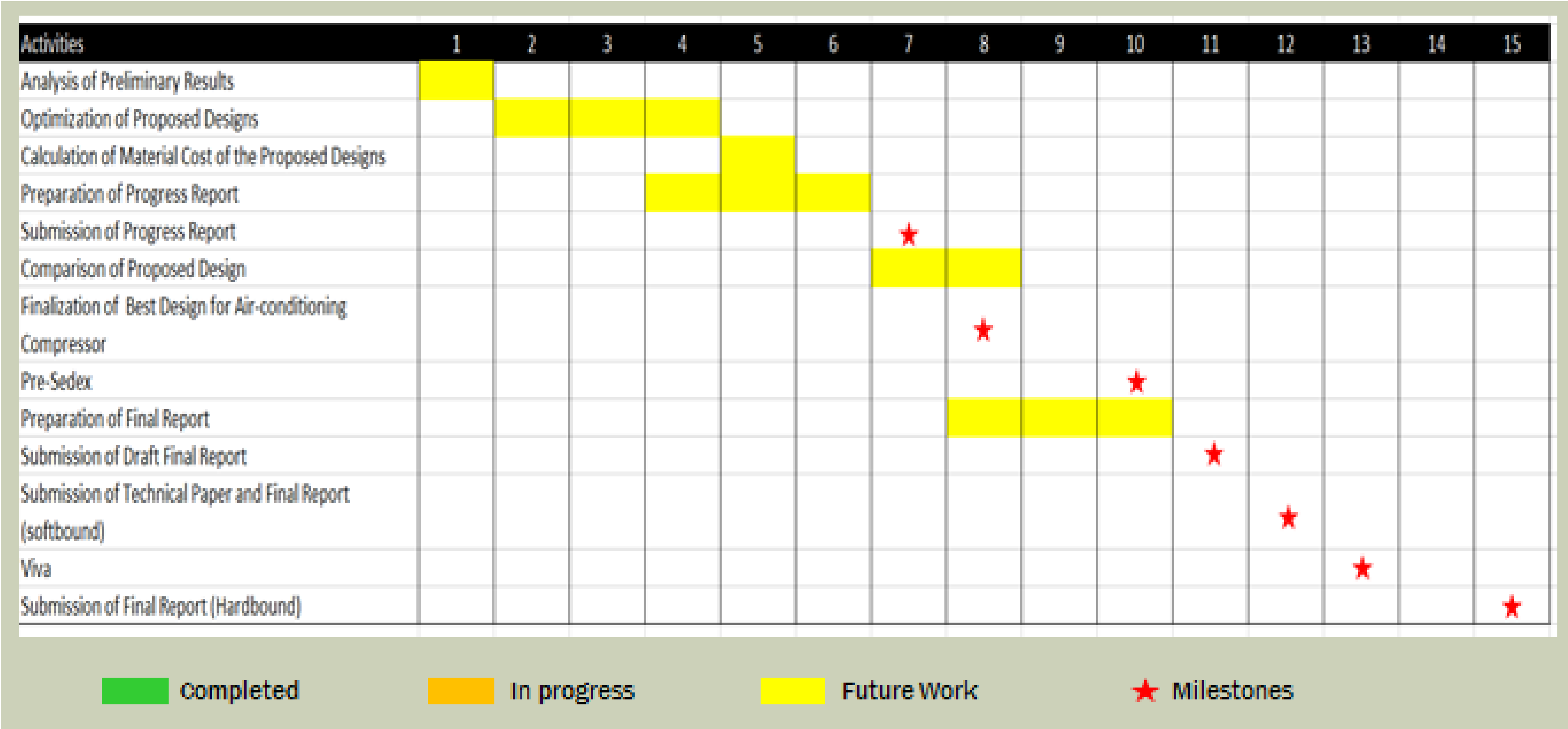

Figure 18 Project Gantt chart and Key Milestones for FYP 2

3.3 CONCLUSION

Chapter 3 represent as the research strategy that need to be done in order to obtain the best result in the given time. The key milestone also be further describe such as the tools is list out such as literature review, the cost analysis and many more. The Gantt chart also had been proposed from semester 1 until semester 2 in order to make sure this research right on track. Besides, ANSYS MAXWELL also stated as it is the main software used in order to complete the research study.

CHAPTER 4

RESULT AND DISCUSSION

4.0 INTRODUCTION

Chapter 4 explain about the results obtained from simulation for six proposed design designs which were rectangular, parallelogram, thalbach, trapezoid, triangle and tshape. The result are divided into four main parts which are flux line, air gap distribution, and cost analysis.

4.1 MAGNETIC FLUX LINE DISTRIBUTION AND AIR GAP FLUX DENSITY

Flux line is very important in order to ensure no saturation occur in the design. It also to ensure the current movement in the magnet shape. The simulation is set in static condition with no current from coil and no movement of the magnet. Hence, the result such as the air gap distribution simulation consists of the flux line and flux density distribution is obtained. Figure 11 shows the flux line of six different magnet for motor design. This is due to finding the best design of magnet shape that can produce efficient linear motor. Overall design seem to form two circles of flux line due to the halbach configuration of the magnet except for radial magnet as it not halbach configuration. Axial magnet represent the horizontal direction while vertical direction represent as radial magnet in flux lines configuration. Figure 11 shows, triangular design produced the best result as it is mostly fully occupied with flux line produced.

However, the different shape and structure of magnet result on different magnetic flux density as the design varied from each other. However, due to the volume assign for the magnet is same, hence flux density, the pattern for each motor is almost same. The color assigned the strength of the magnetic flux density, red shows the highest and blue shows the lowest density for each design

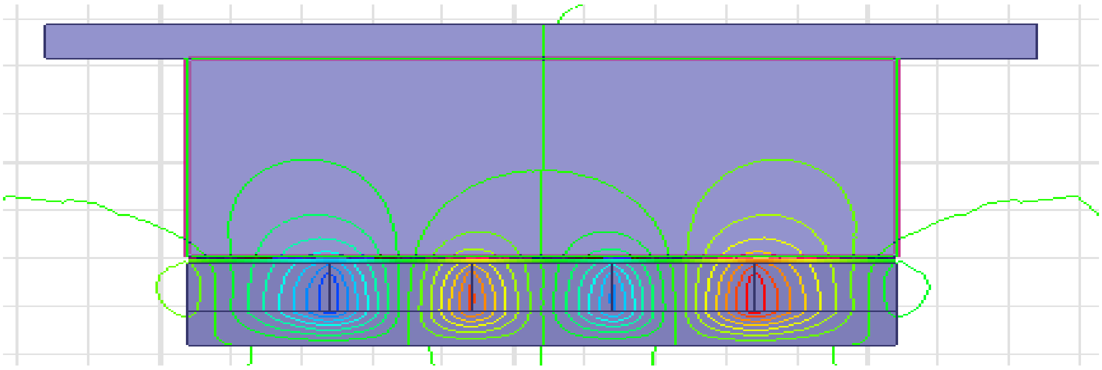

Figure 19 Rectangular flux line

Figure 18 shows rectangular flux line. The flux line of rectangular shows symmetrical and smooth. It is not distorted. Hence, this design is the best design to be simulate to obtain the result.

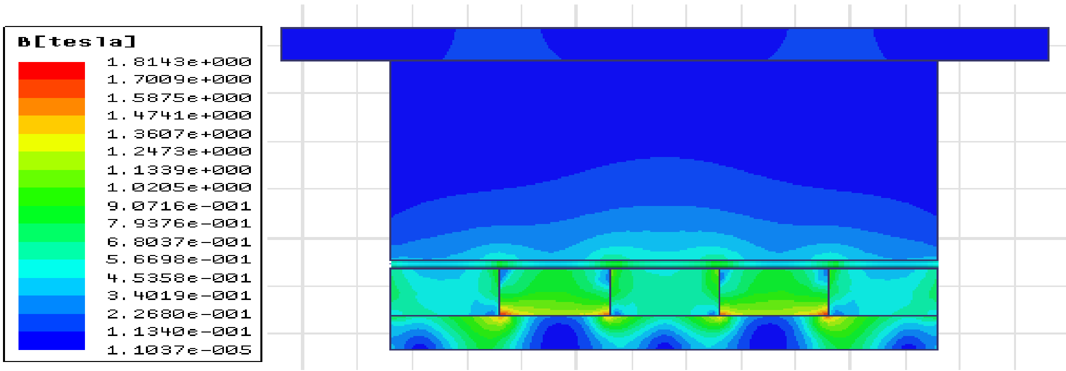

Figure 20 Rectangular air gap density

Figure 19 shows the air gap density shows that there is less density of the magnetic flux density as the colour of the red is less and blue color is high.

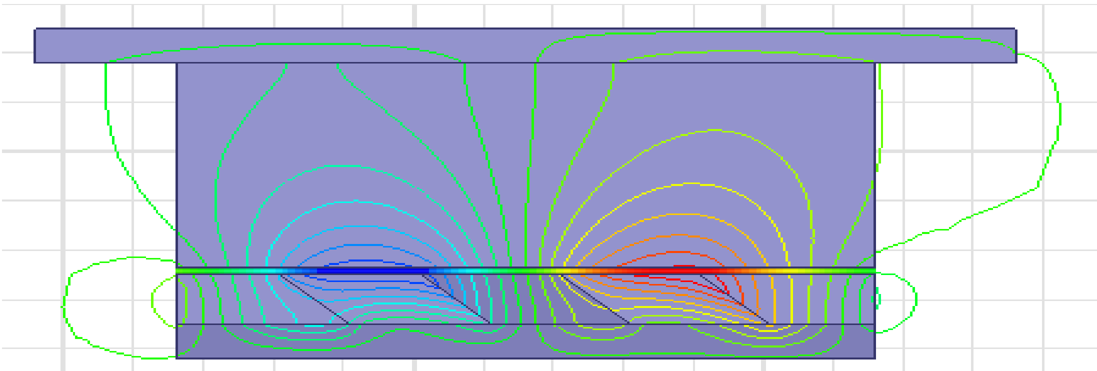

Figure 21 Parallelogram flux line

Figure 20 shows parallelogram flux line. The flux line of parallelogram shows that is the best design can be show as it is nearly symmetrical. It is not distorted. However, the flux line is smooth. Hence, this design is the best design to be simulate to obtain the result.

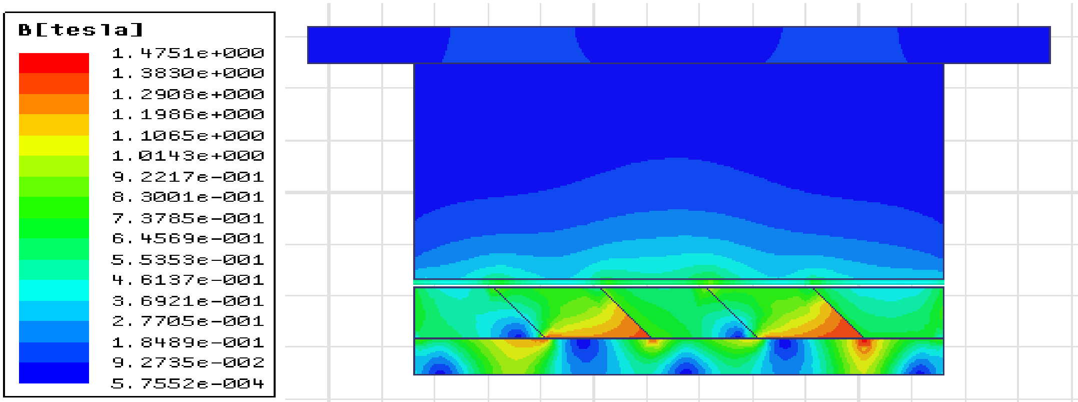

Figure 22 Parallelogram air gap density

Figure 21 shows the air gap density shows that there is high density of the magnetic flux density as compare with rectangular shape as the red colour is a bit show up. However, the density of the magnetic flux still less as more blue appear.

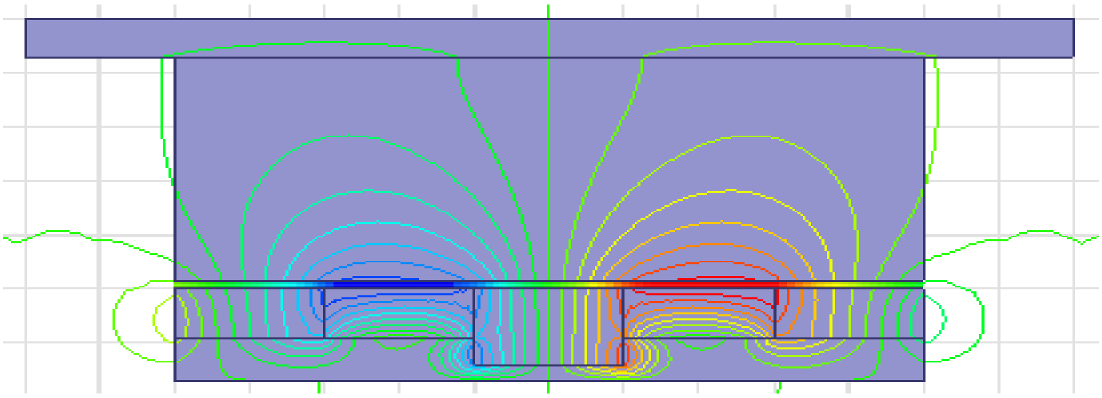

Figure 23 T-Halbach flux line

Figure 22 shows thalbach flux line. The flux line of thalbach shows that it has the best design symmetrical and smooth. It is not distorted. Hence, this design is the best design to be simulate to obtain the result.

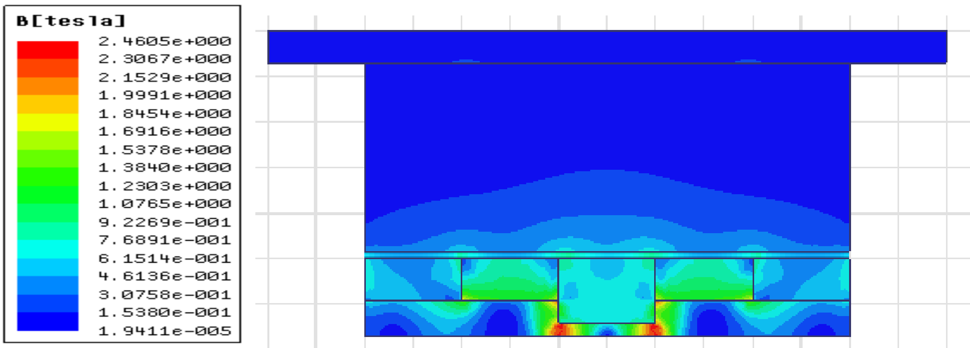

Figure 24 T-Halbach air gap density

Figure 23 shows the air gap density shows that there is less density of the magnetic flux density as compare with parallelogram shape as the red colour value of parallelogram is hiher than in thalbach.. However, the density of the magnetic flux still less as more blue appear.

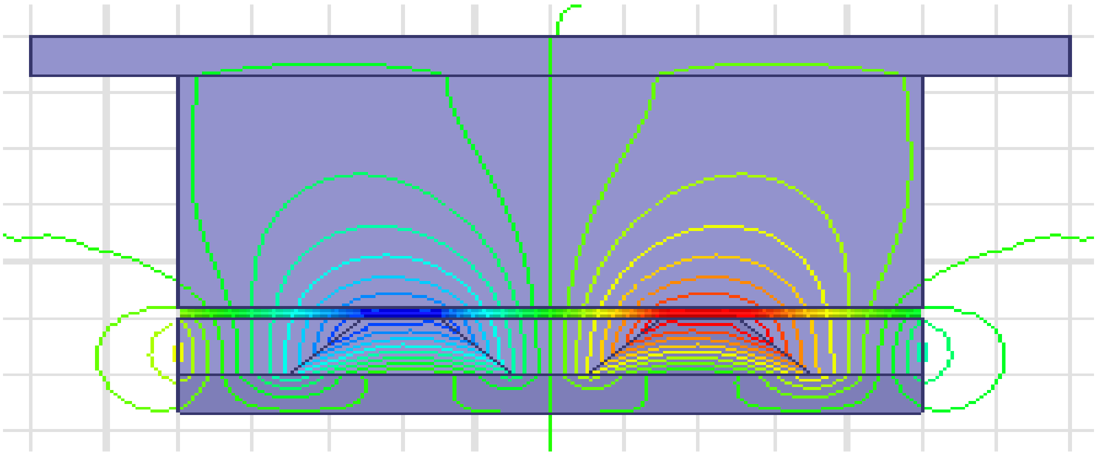

Figure 25 Trapezoid flux line

Figure 24 shows trapezoid flux line. The flux line of trapezoid shows that it has the best design symmetrical and smooth of these parameter. It is not distorted. Hence, this design is the best design to be simulate to obtain the result.

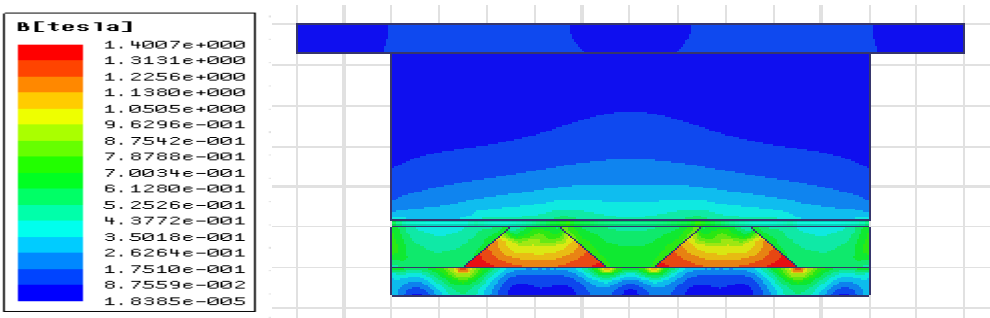

Figure 26 Trapezoid air gap density

Figure 25 shows the air gap density shows that there is less density of the magnetic flux density as compare with parallelogram and thalbach shape as the red colour value is less. However, it has higher magnetic flux density compare with rectangular.

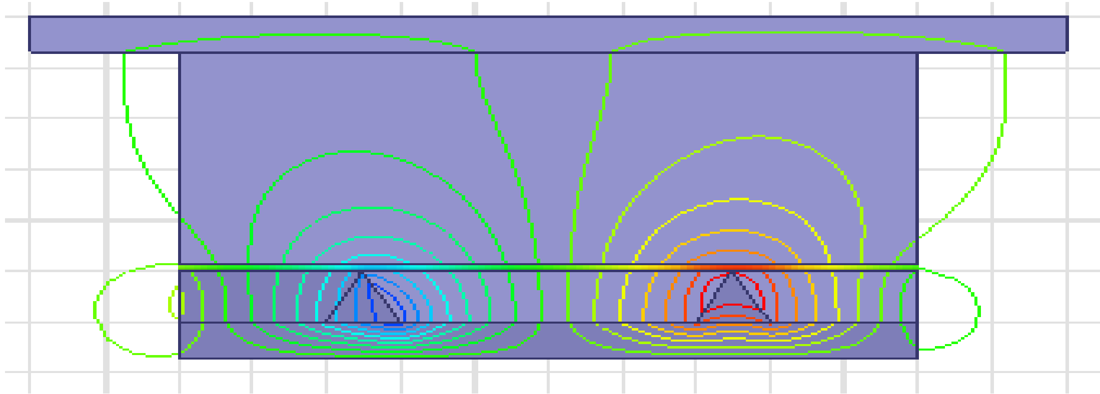

Figure 27 Triangle flux line

Figure 26 shows triangle flux line. The flux line of triangle shows that it has the best design symmetrical and smooth among other parameter. It is not distorted. Hence, this design is the best design to be simulate to obtain the result.

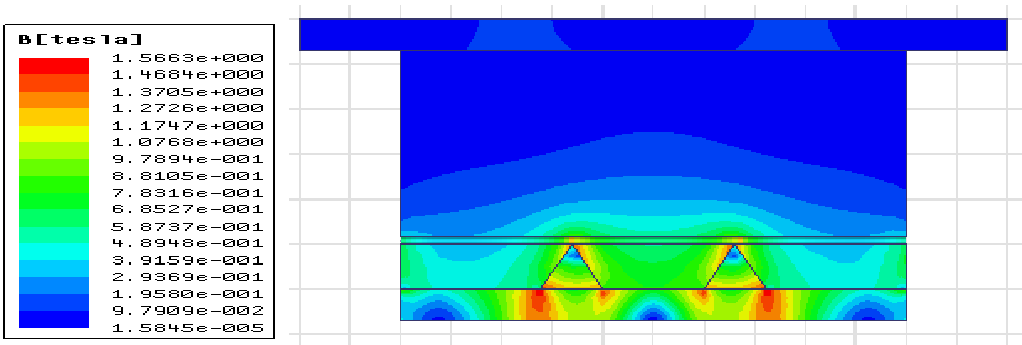

Figure 28 Triangle air gap density

Figure 27 shows the air gap density shows that there is high density of the magnetic flux density as compare with trapezoid shape as the red colour value is high. However, the density of the magnetic flux still less as more blue appear.

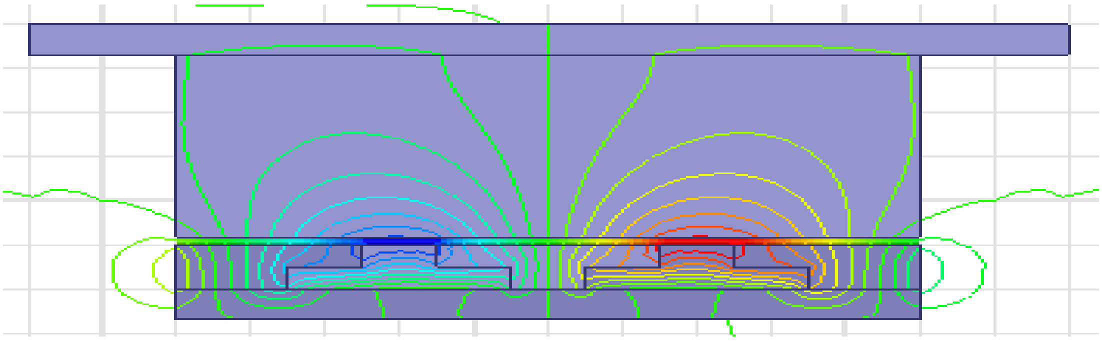

Figure 29 T-Shape flux line

Figure 26 shows tshape flux line. The flux line of tshape shows that it has the best design symmetrical and smooth among other parameter. It is not distorted. Hence, this design is the best design to be simulate to obtain the result.

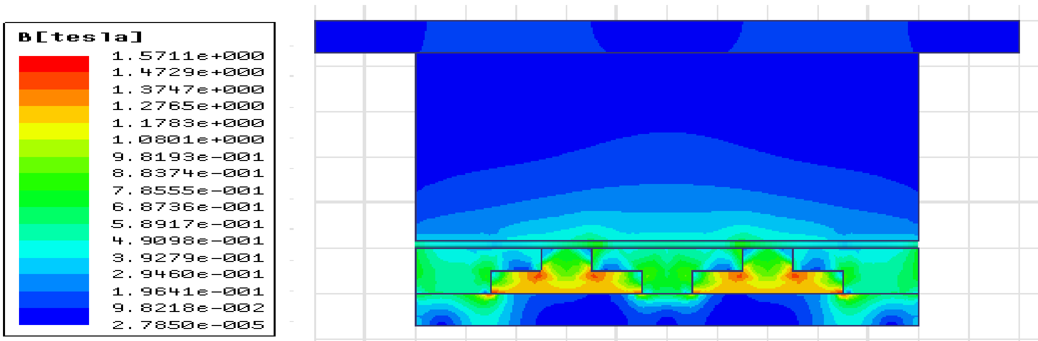

Figure 30 T-Shape air gap density

Figure 29 shows the air gap density shows that tshape has the highest density of the magnetic flux density as compare with other magnet shape as the red colour is the highest.

Figure 31 Magnetic flux line and magnetic flux density for each proposed designs

4.2 MAGNETUDE OF FLUX LINE

Figure 12 and table 1 show the comparison of flux line value along the axial position of the permanent magnet of the six proposed designs. Based on the six proposed design, the volume, shape and halbach configuration are the same. However, only the magnet shape different. Result shows that the parallelogram shape has the highest flux line followed by thalbach and triangle shape. This is proved that design is occupied with flux at all places since these design has large surface for the radial magnet shape to the stator compare with other design. Hence, the high flux line will produced high induced voltage.

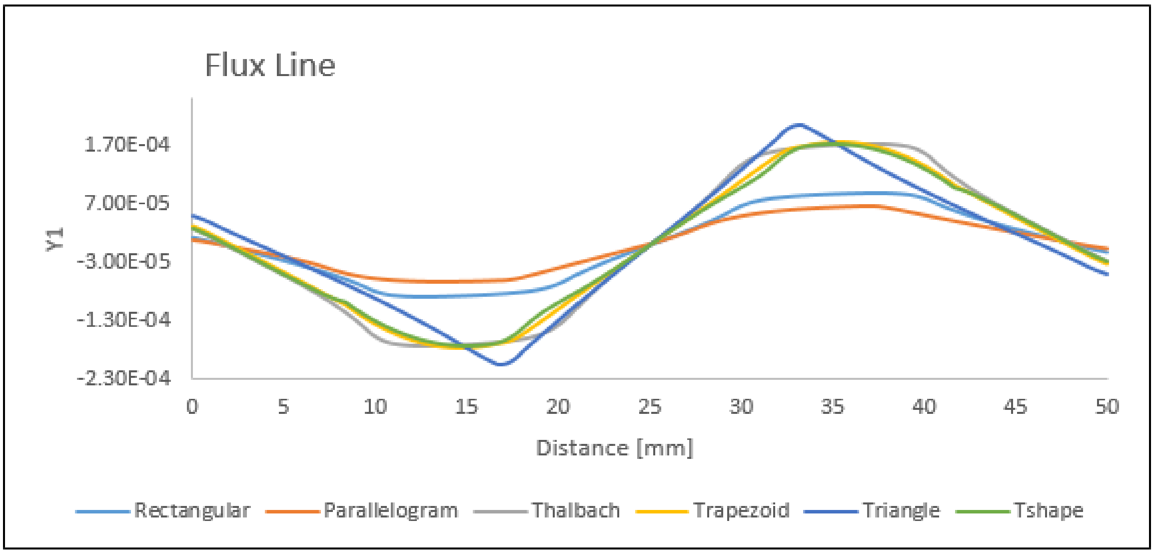

Figure 32 Flux line vs axial position

Table 3 Average value and maximum value for six proposed designs

Flux Line	Rect-angular	Parallelo-gram	Thalbach	Trapezoid	Triangle	Tshape
Average value	6.37644E-12	2.21E-07	2.78091E-08	6.3032E-10	6.63836E-09	4.22026E-09
Maximum value	8.81589E-05	6.53E-05	0.000171446	0.0001771 5	0.000203889	0.000173

4.3 MAGNITUDE OF FLUX DENSITY

Figure 32 and table 4 shows the comparison results for flux density between six proposed designs in term of flux density between the airgap for six proposed design. The higher the flux density means, the higher magnitude of induced voltage passing through a unit area. Based on the average value obtained, the results shows that triangle shows the best result followed by thalbach, parallelogram and tshape value. Therefore, the best flux density is triangle shape which can produced higher back emf of the motor as it has higher flux density.

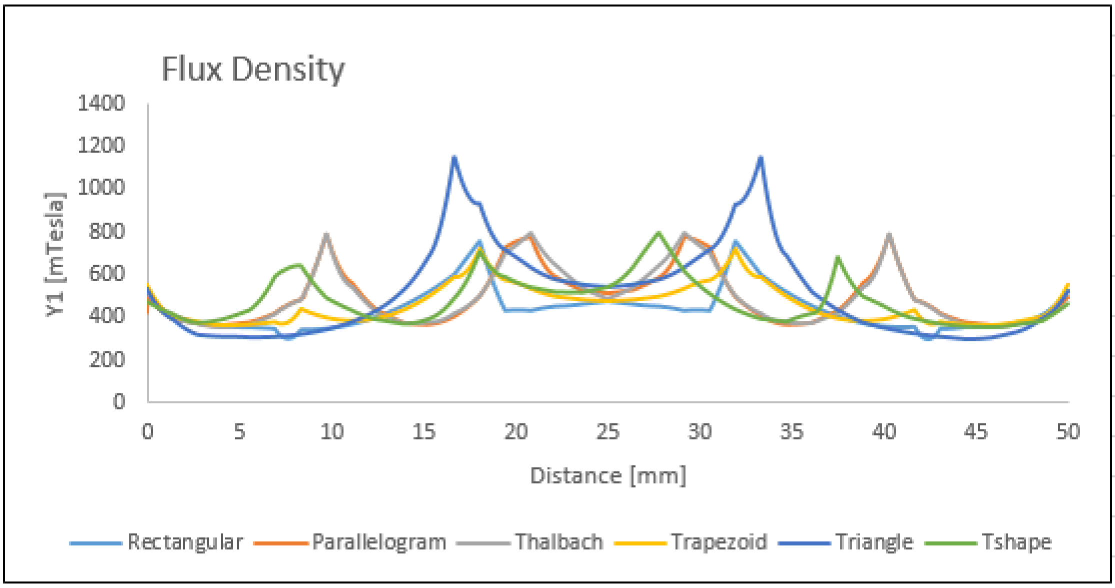

Figure 33 Flux distribution vs axial position

Table 4 Average value and maximum value for six proposed designs

Flux Line	**Rect-angular**	**Parallelo-gram**	**Thalbach**	**Trapezoid**	**Triangle**	**Tshape**
Average value	437.4944	497.2129	497.9757	459.5158	519.3013	477.1538
Maximum value	756.496	786.3592	799.1275	718.3962	1153.196	796.159

4.4 MAGNITUDE OF FLUX LINKAGE

Figure 33 and table 5 shows the result obtain from comparison of flux linkage between six proposed designs. When flux linkage is high, the magnetic flux linked or near the coil will increase the field strength with the coil area. From the results obtained, the parallelogram shape has the highest flux linkage followed by thalbach shape. Therefore, the parallelogram shape produced higher induced voltage which is the most efficient magnetic shape.

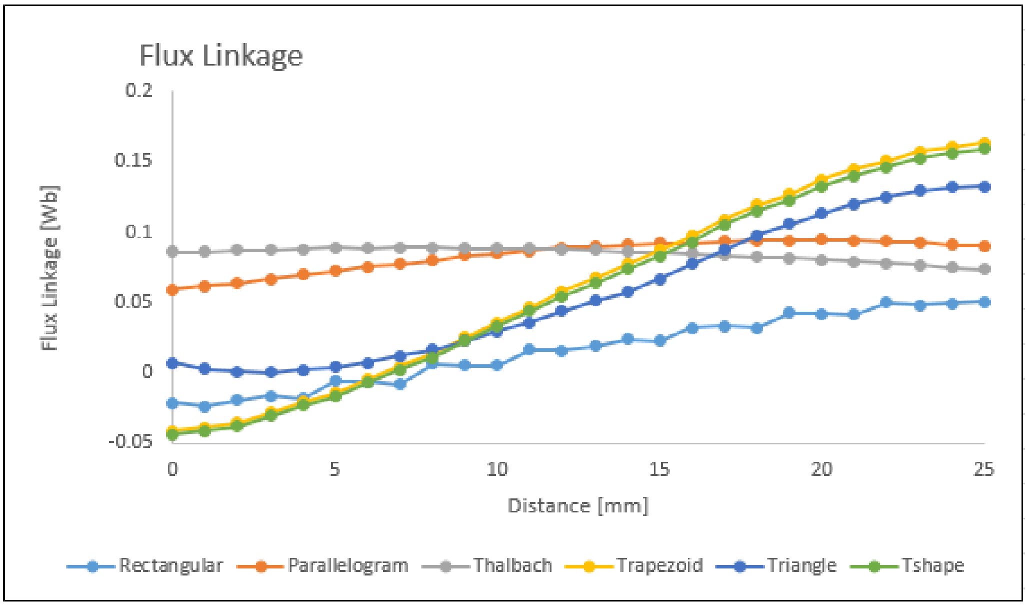

Figure 34 Flux linkage vs axial position

Table 5 Average value and maximum value for six proposed designs

Flux Linkage	**Rect-angular**	**Parallelo-gram**	**Thalbach**	**Trapezoid**	**Triangle**	**Tshape**
Average value	0.015968	0.083624	0.08454	0.061551	0.05697	0.058098
Maximum value	0.050853	0.094848	0.089255	0.163749	0.132805	0.159527

4.5 MAGNITUDE OF INDUCED VOLTAGE

Six proposed design have different induced voltage. Induced voltage or back emf is produced by movement of magnet or changing in magnet. If the flux line increase, the flux density increase, and the flux linkage increase hence high induced voltage is produced. Figure 34 and table 6 shows that parallelogram shape gives the highest induced voltage followed by thalbach shape, triangle and tshape. According to Faraday's Law, the induced voltage produced depends on the flux linkage.

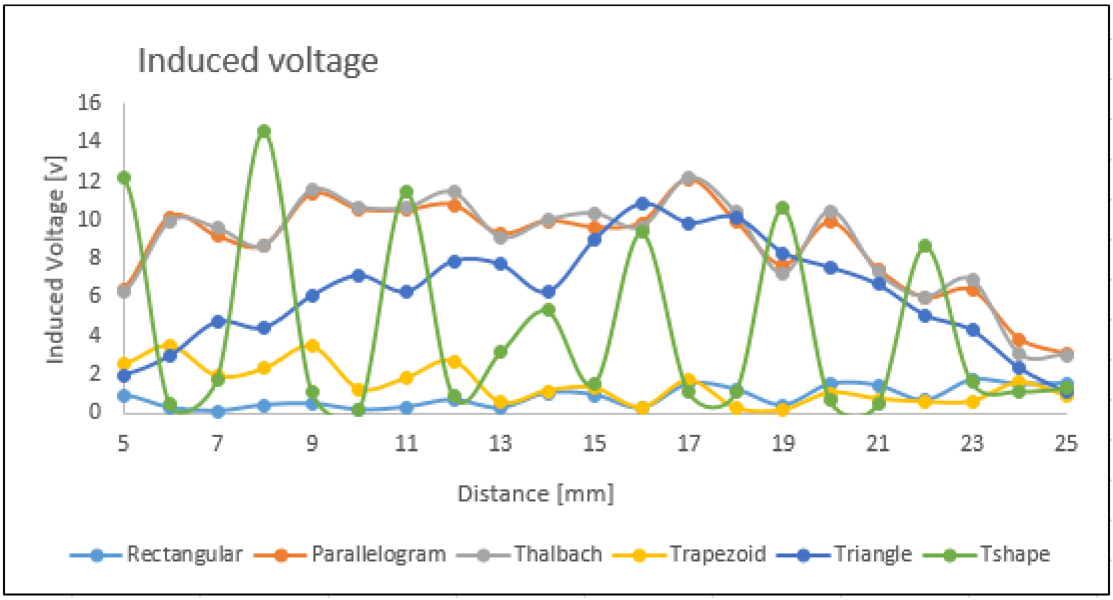

Figure 35 Induced voltage vs axial position

Table 6 Average value and maximum value for six proposed designs

Induced voltage	**Rect-angular**	**Parallelo-gram**	**Thalbach**	**Trapezoid**	**Triangle**	**Tshape**
Average value	0.758184	7.814385	7.877312	1.568258	5.37375	3.875836
Maximum value	1.734699	12.12769	12.21885	3.515042	10.84886	14.55733

4.6 COST ANALYSIS

Each type of design have different cost analysis. The cost analysis formula is calculated based on the following formula

Price = Density x Weight x Price per Kg

Calculation shown in table is not including the cost for the whole linear motor for the air conditioning compressor system. It only shows the calculation obtained for the materials costs only. This also due to different type of magnet give different type of cost. Table 7 and Table 8 show the price, density and volume for each materials and designs. Among this six proposed design, rectangular shows the cheap price compared to other proposed design.

Table 7 Price and density of each material

Materials	**Price MYR/kg**	**Density Kg/m^3**
Copper	22.69	8230
Steel	1.27	7800
Neodymium Iron	290.50	7500
Iron	0.90	7870

Table 8 Volume of each linear motor design

Design	Volume of material (m^3, E-03)			
	Copper	Steel	Magnet	Iron
Rectangular	2.1	6.94	3.04	1.66
Parallelogram	2.1	6.94	3.04	1.66
Thalbach	2.1	6.94	3.04	1.66
Trapezoid	2.1	6.94	3.04	1.66
Triangle	2.1	6.94	3.04	1.66
Tshape	2.1	6.94	3.04	1.66

As per calculated as in Table 8, the volume of six design of linear motor is similar as it is fix volume. The volume will be change once the optimization will be done as the volume of it will be changed based on the axial position to obtain the best efficient topology of magnet.

Table 9 Price of each linear motor design

Design	Price of material (MYR)				
	Copper	Steel	Magnet	Iron	Total
Rectangular	354.8	68.75	6623.4	11.76	7058.71
Parallelogram	354.8	68.75	6623.4	11.76	7058.71
Thalbach	354.8	68.75	6623.4	11.76	7058.71
Trapezoid	354.8	68.75	6623.4	11.76	7058.71
Triangle	354.8	68.75	6623.4	11.76	7058.71
Tshape	354.8	68.75	6623.4	11.76	7058.71

As per calculated as in Table 9, the price of six design of linear motor is same as its volume is same. The price will be varied as optimization will be done.

4.7 **CONCLUSION**

Chapter 4 explained the preliminary results obtained from the simulation by making comparison on the performance of six proposed design. It can be concluded that parallelogram shape, triangle shape and Thalbach shape obtain among top three highest induced voltage that is produced and suit for this preliminary result. Based on the preliminary results, the parallelogram shape and thalbach shape shows the constant and reliable result compared to other proposed design. However, when considering the cost of the magnet, among the slightly higher price compare with other design.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

As a conclusion, this study is a clear overview on the power consumption of air conditioning. In this study, a modified electrical machine of compressor was proposed by simulate it using the finite element analysis. Electrical machine can be improved by design the structure of the air conditioning such as design outcome (flux distribution, air gap flux density, flux linkage and back emf). From the simulations, finite element analysis has been performed to justify the proposed design motor for compressor to reduce usage power consumption of air conditioning. Finite element analysis has been performed to justify the proposed design outcome that can combined the conventional motor of compressor with linear electrical machine using software. Hence, it is necessary to research on the linear electrical machine with the conventional compressor in order to simulate the accurate exerted to produce a cost effective design. From the result obtained, we can concluded that different shape of magnet result on different output. The higher the flux density and flux line magnitude, the higher the induced voltage and flux linkage that will produce.

5.1 RECOMMENDATION FOR FUTUREWORKS

Improvements that can be made to reduce the problems are in the motor itself which is in the compressor inside the air conditioner. The rotary motors have been used largely nowadays compared to linear motors due to their better performance and low cost based on research made. However, rotary motor do not have some of the advantages that linear motor can give. Nevertheless, the linear motor also has some of the downside that make people used more of rotary motor. Hence, it is proposed that linear motor is combined with the rotary motor to get both advantages to be used in a conditioner system inside the compressor.

REFERENCES

[1] E.Sulaiman, S.A.Jumaat, M.Ishak, M.A. Chulan And S.Saiman ‘’A Study on Electric Energy Usage at the Residential Area,” in 1st Engineering Conference on Energy and Environment, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (2007).

[2] T.Kubota, S.Jeong, D.H.C. Toe, and D.R. Ossen. “Energy Consumption and Air Conditioning Usage in Residential Building of Malaysia’’ in International Development and Cooperation, Faculty of Electrical and Electronic Engineering , Universiti Teknologi Mara Malaysia Volume 17(13) 2011: 61-69

[3] A.A. Azlina, E. S. Z. E. Abdullah, M. Kamaludin, A. A. Radam, “Energy Conservation of Residential Sector in Malaysia, ” in Business and Social Development Volume 3(2) 2015: 51-62.

[4] S.K.Wang, “Handbook Of Air Conditioning And Refrigeration, 2nd. Ed. United States of America: Mcgraw-Hill, 1993: Classification of Air Conditioning Systems According to Construction and Operating Characteristics” 2000: 41-49.

[5] Natural Resources Canada’s, Office of Energy Efficiency and Energuide “ Air Conditioning Your Home:French 1996 Types of Air Conditioning” in Publication Data, Canadian Cataloguing 2004: 14-31

[6] Alert, Daily and Daily Alert (19 October 2016) "Working Principles Air Conditioner - How It Works?" *My Daily Alerts*. N.p., 2016. Available: http://mydailyalerts.com/working-air-conditioner-air-conditioner-work

[7] M. Isakki Muthu, S. Chellappa, “Refrigeration And Air Conditioning, Petaling Jaya IBS Book 2007 ” in Information Research Centre, 2007:1-66.

[8] Energy Design Resources, “Chilled Water Plant Design Guide,’’ in Manual Book Cooltools 2009: 1-45

[9] RSES “Heating, ventilation, air conditioning and refrigeration,” RSES Journal, July 2009 Available: http://www.rses.org/journal.aspx

[10] N. F. Zulkarnain, T. Ibrahim and H. Z. Hashim , " Design and modeling of electrical machine for ceiling fan system" Universiti Teknologi Petronas, Malaysia. *Volume* 10(21) Nov, 2015.

[11] J. Puranen, Induction Motor Versus Permanent Magnet Synchronous Motor in Motion Control Applications Findland 5th. ed. Finland 2006 "A Comparative Study: Permenant Magnet Synchronous Motor in Servo Drives" , in University Technology Lappeenranta 2006:34-57.

[12] A.M.Eid, H-W. Lee, and M. Nakaoka, "Cogging Force Minimization of Linear Engine-Coupled Tubular Permanent Linear AC Synchronous Generator, " in The 3rd IET International Conference on Power Electronics, Machines and Drives, 2006: 116-120.

[13]I. Ivanova, O, Agren, H. Bernhoff, and M. Leijon, " Simulation Of Cogging In A 100 kW Permanent Magnet Octagonal Linear Generator for Ocean Wave Conversion, ' in Underwater Technology, 2004. UT04, 2004 International Symposium on, 2004: 345-348.

[14] A. Demenko, G. Co-editor: Kay Hameyer, S.Kuling, I. Nowak, K. Zawirski, T.S. Parel, et al. " Optimization of A Tubular Linear Machine With Permanent Magnets for Wave Energy Extraction and Mathematics in Electrical and Electronic Engineering, Volume 30, 2011: 1056-1068.

[15] Neethu, S., K.S. Shinoy, and A.S. Shajilal. "Efficiency Improvement of An Axial Flux Permanent Magnet Brushless DC Motor for LVAD Application". Applied Mechanics and Materials 110-116 (2011): 4661-4668.