WASTE HEAT RECOVERY FROM EXHAUST GAS USING STEAM TURBINE MECHANISM

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declared that this project entitled "Waste Heat Recovery from Exhaust Gas Using Steam Turbine Mechanism" is the result of my own work except as cited in the references

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

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluid)

Signature :...................................

Name of Supervisor :...................................

Date :...................................

DEDICATION

To my beloved

Father and Mother

Pakhrazi Bin Ishak

&

Ume Khalsom Binti Salleh

ABSTRACT

Nowadays, Internal Combustion Engine (ICE) is used in most vehicles around the world as their system. ICE is one of the most inefficient systems for vehicles because most of the energy burned from the fuel is wasted to heat, mechanical and other losses. Either realizes or not, only 15 percent of the energy from the fuel is used to move the vehicles or run useful accessories. To recover the energy losses, Waste Heat Recovery (WHR) mechanism can be used. The mechanism recycles the wasted energy from the vehicle into power as electric current. Exhaust system of the vehicle play the important role in this mechanism, where the power produce for this mechanism is used the wasted heat from the exhaust. The exhaust will cover with good insulator to prevent the heat produced loss to the surrounding. The current produced can be stored in the battery. The electric energy also can be used as the source of energy for the hybrid vehicles. This project is considering the performance of the vehicle when equipped with the WHR system and not the power produced and its storage.

ABSTRAK

Pada masa kini, Enjin Pembakaran Dalaman (EPD) digunakan dalam sistem kebanyakan kenderaan di seluruh dunia. Enjin Pembakaran Dalaman (EPD) adalah salah satu sistem yang paling efisyen untuk kenderaan kerana pembaziran terhadap sebahagian besar tenaga yang dibakar dari bahan api kepada haba, mekanikal dan pembaziran lain. Sama ada sedar atau tidak, hanya 15 peratus daripada tenaga daripada bahan api yang digunakan untuk menggerakkan kenderaan atau aksesori digunakan. Untuk memulihkan pembaziran tenaga tersebut, mekanisme Waste Heat Recovery (WHR) boleh digunakan. Mekanisme ini mengitar semula tenaga yang terbazir dari kenderaan ke dalam kuasa sebagai arus elektrik. Sistem ekzos kenderaan memainkan peranan yang penting dalam mekanisme ini, di mana hasil kuasa untuk mekanisme ini menggunakan haba yang terbazir dari ekzos. Ekzos akan ditutup dengan penebat yang baik untuk mengelakkan haba yang dihasilkan terbazir kepada sekitarnya. Aliran elektrik yang dihasilkan boleh disimpan di dalam bateri. Tenaga elektrik juga boleh digunakan sebagai sumber tenaga untuk kenderaan hibrid. Projek ini sedang mempertimbangkan prestasi kenderaan apabila dilengkapi dengan sistem WHR dan tidak menumpukan kepada kuasa yang dihasilkan dan penyimpanan.

ACKNOWLEDGEMENT

Thanks to god upon the completion of this report. I would like to express my deepest appreciation to my supervisor En. Safarudin Gazali Herawan for giving me this opportunity to do final year project with him. He never hesitated to give me advice and guidance whenever I confronted problems. I am thankful for his patience and advice while leading me in this project.

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CCPP	Combination Cycle Power Plant
ABC	Air Bottoming Cycle
EMF	Electromotive Force
WHRM	Waste Heat Recovery Mechanism
ICE	Internal Combustion Engine
PM	Permanent Magnet

CHAPTER 1

INTRODUCTION

1.1 Background

Every combustion engine has their excessive output called as exhaust gas. Exhaust gas produced after the engine completing one cycle of combustion process. Usually, this gas will be released directly to the environment. This type of gas has high temperature that can be reused as an input to generate electricity. This process called as Waste Heat Recovery which is in this process, the waste heat from the exhaust gas is used to spin a turbine and rotate the generator to produce electric energy output as the result. There are three main components used to create this recovery system. Those are heat exchanger, gas turbine and generator.

Heat exchanger is a device used for transferring thermal energy between two or more working fluids which is transfer heat from one flow of medium without any physical contact or mixing the two media. (Kim et al., 2009). Normally, heat exchanger related to two different temperature of streams which are hot stream and cold stream. There usually no external heat and work interactions in heat exchanger. Basic applications of heat exchanger involve heating or cooling of a fluid stream. For instance, steam generator, feed water heater, reheaters and condensers are all examples of heat exchangers found in our industry. (Reay, D. A., 1999).

Gas turbine is one of the basic technologies used to produce electricity. Gas turbine also have a lot of advantages such as fast start up turbine, high efficiency, low pollutants emissions, and have a reasonable size. The gas turbine is combination of cycle power plant (CCPP). There are two means in cycle power plant (CCPP) which area air bottoming cycle (ABC) and recuperator. Recuperator used to utilizes the heat of exhaust gases of topping cycle to heat the compressed air that delivered from compressor of ABC. (O Bolland, M Forde, B. Hande, 1996). This concept of gas turbine has been well established by the 1970s. In such a cycle, the hot exhaust gases from the gas turbine are passed through the HRSG where they produce superheated steam in a bottoming cycle to produce power output. (J. H. Horlock, 1995). Normally, the exhaust stream temperature of open cycle gas is around 500 ºC. So that, this system is very suitable for heat recovery application to improve cycle efficiency.

Generator is a system that induces a voltage between the loop terminals by spinning a wire loop within a uniform magnetic field in a convenient fashion. The induced voltage influenced by the rotation speed. The higher the rotation, the higher the voltage induced. Generator can produce an electrical load with the desired type of current which are Direct Current (DC) and Alternating Current (AC). For DC generator is called as dynamos while AC generator called as alternator. The basic generator only can produce Alternating Current (AC). To convert into Direct Current (DC), it must have a device working as a mechanical rectifier that used as the collector. (Chapman, Stephen J, 1985). Figure 1 shows the example of a few type of generator.

Figure 1 Two type of generator with different power input

1.2 Problem Statement

Free energy concept can be described when the energy can be generated by electromagnetic force of magnet when using any input from free waste source. The definition of free energy is not the same as natural free energy source such as solar, wind, hydro or geothermal energies. This is because these electromagnetic force machine requires some input energy to produce an increased output, which the natural source do not require. Some electromagnetic machine can produce an output only slightly above unity, while others have produced output about three to one. But lately, there are a lot of inventors that created the electromagnetic machine with the output of the machine produced until about five to one.

This project will be conduct to determine the amount of the output power can be generated from the waste heat from exhaust gas by using the steam turbine generator. A steam turbine generator will be installed near the exhaust manifold of a project car to generate electricity energy output. The generator used the excessive waste heat from the exhaust as the input to spin the turbine and rotate the generator. Since, the current generator is not efficient enough to generate the electricity energy, so this project will continue to make the improvement on the generator to increase the output energy to achieve target which is can produce current more than 3.5 A and voltage more than 24 V at normal driving in rural environment.

1.3 Objective

The objectives of this project are as follows:

1. To study and determine the best design for the steam turbine generator to increase the efficiency of the generator.
2. To study the relationship between the number of coil turn, the diameter of the turn, and the diameter of the coil with the efficiency of the generator.
3. To fabricate the generator with high efficiency.
4. To improve the amount of the output voltage that can generated from generator.

1.4 Scope of Project

The scopes of this project are:

1. Study on the application of electromagnetic force and how to produce a high power output.
2. There are few type of design will be used to create the generator in order to increase the power output of the generator.
3. Power input and type of turbine will be fix during this project to measure the efficiency of the generator.

1.5 General Methodology

The actions that need to be carried out to achieve the objectives in this project are listed below:

1. Literature review

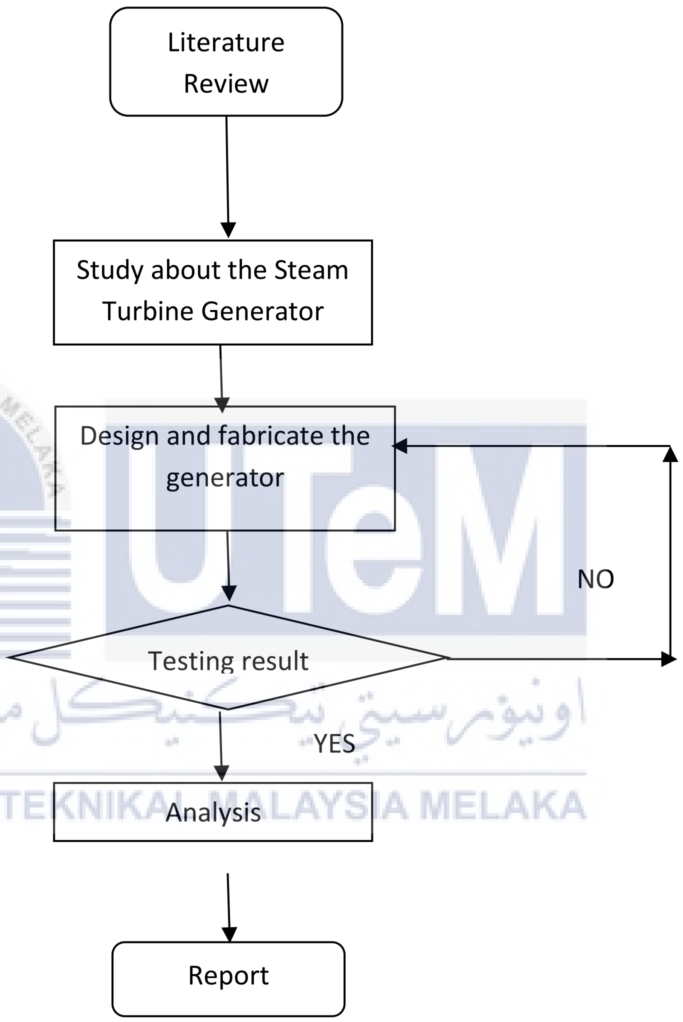
   Journal, articles, web or any material regarding this project will be reviewed.
2. Experimental

   Experiment will be conducted to collect the data regarding the output power generated from the steam turbine generator.
3. Analysis

   Analysis will be carry on to improve the output power of the steam turbine generator.
4. Report writing

   A report writing for this project will be written at the end of this project.

The methodology of this study is summarized in the flow chart as shown below.



CHAPTER 2

LITERATURE REVIEW

2.1 Review of Thermodynamics

Steam control era has reliably been founded on the Rankine cycle or its adjustment. Be that as it may, with a specific end goal to completely comprehend its working standards, it is helpful to present the Carnot cycle to begin with, since it represents the beginning stage for all the accompanying investigations (Capano, 2014).

2.1.1 Carnot Cycle

Nicolas Sadi Carnot (1769-1832), a French military designer, the individual that capable to present the idea of thermodynamics. The fundamental reason for the idea is to decide the framework which could work at greatest efficiency by utilizing heat at constant temperature that have four change stage, two isothermal and two adiabatic.

Figure 2.1 that shows the cycle on a T-s diagram, the transformations that take place are:

1→2: Reversible adiabatic compression (isentropic). Work is done on the fluid.

2→3: Constant temperature evaporation. The working fluid receives heat from an external source.

3→4: Reversible adiabatic expansion (isentropic). The working fluid generates useful work.

4→1: Constant pressure and temperature condensation. The fluid is giving off heat to the environment and returns to the initial conditions.

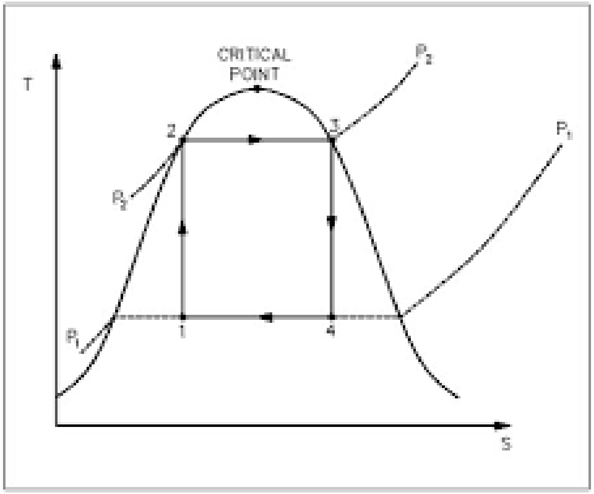


Figure 2 Carnot cycle on T-s diagram
(Gianmarco Capano, 2014)

Carnot cycle efficiency can be acquired from the highest cycle that can be accomplished by whatever other cycle that working inside the same range of temperature, additionally characterized as:

$$\eta_{carnot} = \frac{Q\,23 - Q\,41}{Q23} = 1 - \frac{Q\,41}{Q23} = 1 + \frac{T-}{T+} \tag{2.1}$$

Where;

- $T+ = T_2 = T_3$ is maximum temperature approached by the fluid to the vaporization temperature
- $T- = T_4 = T_1$ is minimum temperature (condensation temperature)

It has been doable to form the last simplification as a result of heat is changed at constant temperature. This expression provides rise to a crucial consideration: even there is no irreversibility within the cycle, the efficiency cannot be equal to 100% unless the low temperature source was at 0K, but, the condition never possible.

Nevertheless, the practicality of Carnot cycle is very difficult because of the problem of elimination of irreversibility in actual process and also difficulties in expanding and compressing partially wet vapor in purely mechanical view. Despite of its thermodynamics advantages, Carnot cycle is not used in any application (Capano, 2014)

2.1.2 Rankine Cycle

Rankine cycle is named from the name of William John Macquorn Rankine (1820-1872), the person who founding contributors to the science of thermodynamics. Rankine cycle represents a practical modification of the Carnot cycle that also known as standard vapor cycle. This cycle used to overcome the limitations in Carnot cycles such as the reversibility. Figure 2.1.2 and Figure 2.1.3 shows the visual representation of Rankine cycle diagram which are T-s and P-h Diagram (Capano, 2014; Condle, 2012).

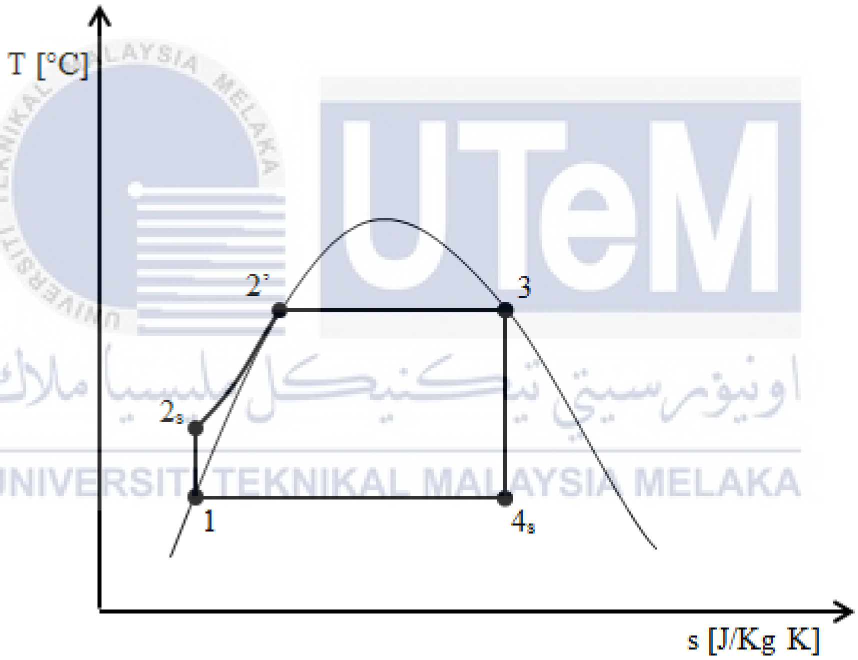


Figure 3 T-s Diagram for Rankine Cycle
(Capano, 2014; Condle, 2012)

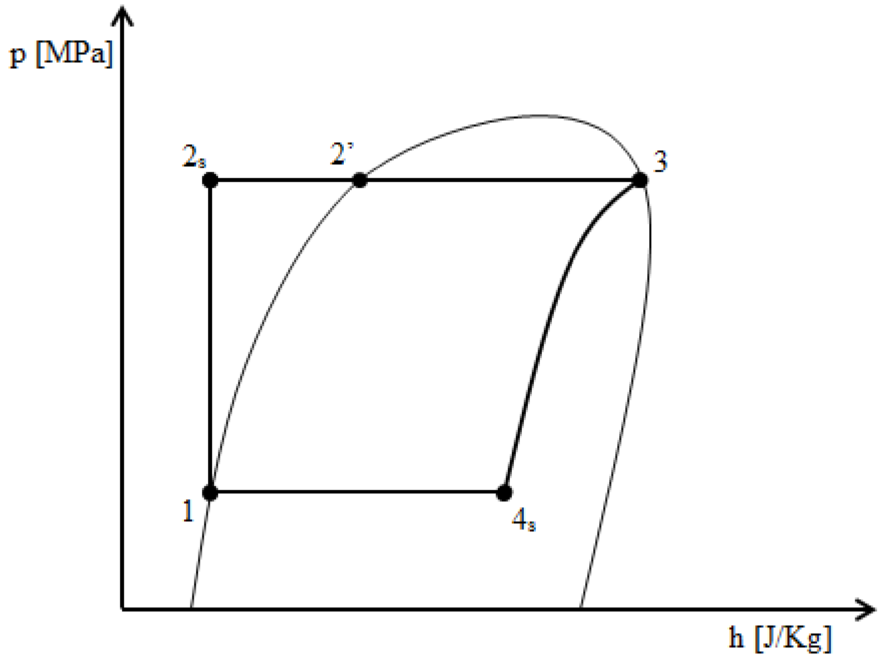


Figure 4 : P-h Diagram for Rankine Cycle

(Capano, 2014; Condle, 2012)

Based on those two figure above, there are a few transformations of the fluid occurred. The processes of the transformations are described below:

1-2 : Isentropic transformations where the low pressure and temperature saturated liquid is compressed up to become high pressure. The work per unit mass required by the pump is equal to the enthalpy difference between point 1 and point 2s;

$$w_{pump} = w_{12s} = \frac{P1-P2s}{P1} = (h_1 - h_2)$$

2s-2 : The high pressure sub-cooled liquid is heated up until it reaches the saturation curve, point 2" at constant pressure,

2'-3 : The constants temperature and pressure liquid is vaporized where the heat per unit mass is absorbed by the flowing fluid between state 3 and state 2s.

3-4s : Isentropic expansion. The high pressure saturated vapor become low pressure.

4s-1 : Condensation process occurred, thus the low pressure vapor turns to its initial condition where the pressure and temperature become constant.

2.2 Waste Heat Recovery in Automotive Industry

For decade, the usage of fossil fuel has been increase continuously by the human activity especially in the production industry. This activity has caused a lot of negative effects to the environment such as global warming, ozone depletion, atmospheric pollution and many more. In order to reduce this side effect and keep our environment health, energy saving activity should be implemented and the best way is introducing new energy conversion technologies. With this kind of technologies, power can be generated without any negative side effect to the nature that already polluted (Capano, 2014).

It One of the larger fossil fuel consumer come from the vehicle that use internal combustion engine (ICE) (Jadhao & Thombare, 2008). ICE also one of the main cause of the increasing of carbon dioxide (CO_2) which can lead to the greenhouse effect and the global climate change associated to this phenomenon. Figure 2.2 shows the average number of CO_2 produced by the vehicle from a few automakers (Capano, 2014; Jadhao & Thombare, 2008).

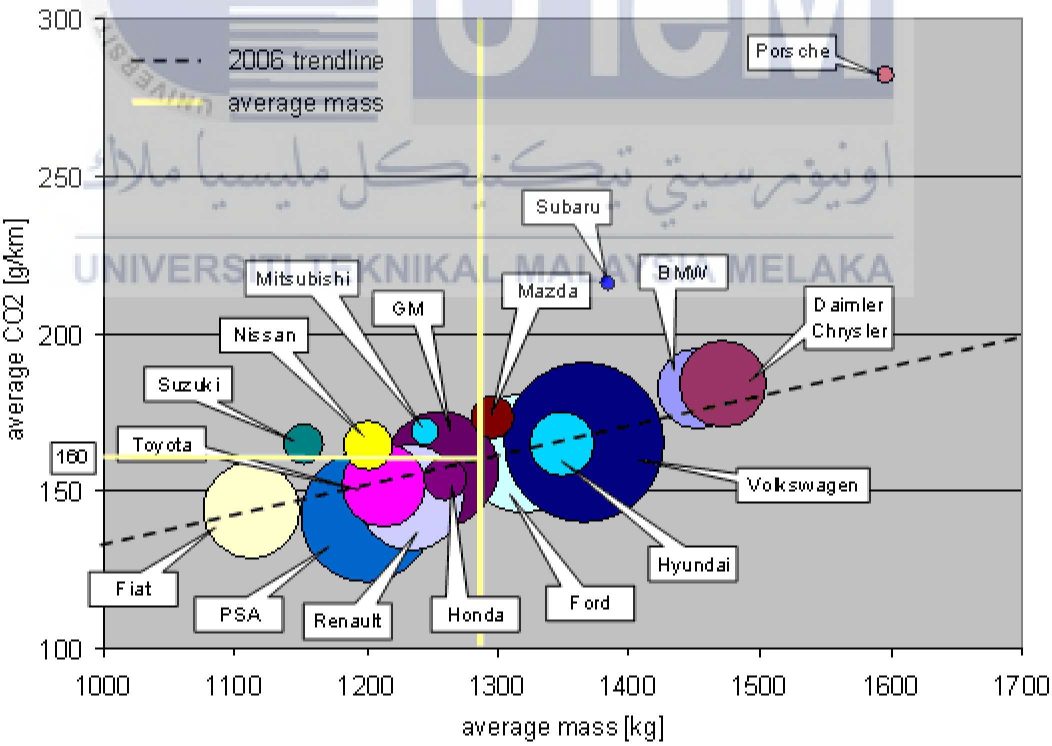


Figure 5 Average CO2 emissions of main car manufacturer in Europe (2006) (Capano, 2014).

In ICE, it is only about 30 to 40% from the fuel usage is converted to the mechanical energy, while others are expelled to the environment through the exhaust gases and engine cooling system (Jadhao & Thombare, 2008). The estimation of the fuel energy wasted through the exhaust is about 21% at the average speed range and the rest is lost in the cooling system (Herawan, Rohhaizan, Ismail, & Shamsudin, 2015). As the energy conversion technologies has been introduced in order to reduce the consumption of fossil fuel and conserved the earth from the pollution and other negative effects, this idea can be implemented in ICE system by utilize the wasted heat energy from the exhaust through the heat recovery system. By developing the heat recovery system, the fuel consumption can be decreased, improve the efficiency and also reduce the greenhouse effect to the environment.

The recent technologies on waste heat recovery of ICE vehicle is consist of low grade heat from cooling system and high grade heat from the exhaust system (Herawan et al., 2015). The low grade heat from the cooling system is not a good choice for the waste heat recovery because of the output temperature is very low, thus it is difficult to harvest. Since the high grade heat from the exhaust system has a very high temperature, it has a larger potential for waste heat recovery and will be the right choice (Ahmad & Amin, 2017). This waste heat recovery has been proved that not only improve the fuel consumption, but also increase the power output of the engine (power density) which was predicted that there is about 10% fuel consumption can reduced, if 6% of the waste heat from the exhaust successfully converted into electrical energy (Capano, 2014).

2.3 Steam Turbine Generator

Many researchers have been studied about the energy saving technologies through Waste Heat Recovery Mechanism (WHRM) from ICE exhaust. There are a lot of applications that can be applied to recover the waste heat energy such as thermoelectric generator, turbocharger, turbo-compound, steam turbine generator and many more (Capano, 2014; Herawan et al., 2015). The previous analysis state that evaporator pressure give better efficiencies compare to others. From those applications about the waste heat recovery, steam turbine generator would be the best application to be explored since the cost is less with the simple construction, while the fuel consumption improvement is also promising (Capano, 2014; Herawan et al., 2015).

For this paper, the study only focus on how to improve the efficiency of the generator so that the number of electrical energy that can be converted throughout the waste heat from the exhaust increase. The main figure about the energy conversion as shown in Figure 2.3.

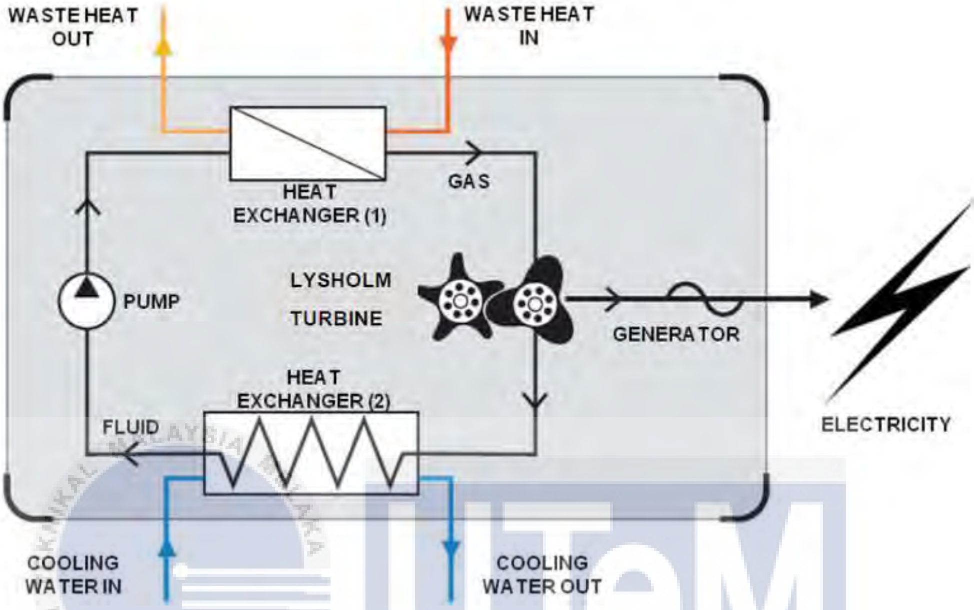


Figure 6 How the electrical energy generated

According to Figure 2.3, the waste heat from the ICE exhaust will enter the heat exchanger region where the fluid from the container is pumped and flowing through. Heat from the exhaust will be absorbed by the fluid and turns the fluid become steam. Then, the high pressure steam will rotate the turbine that connected itself with a DC generator. The rotation of the generator will generate the output electrical energy that can be stored in the secondary battery or capacitor (Herawan et al., 2015). In this WHRM application, there are 3 main parts that can affected much the output of electrical energy produced. Those are heat exchangers, turbine and DC generator. This paper only focus on how to improve the efficiency of the generator in order to generate more power output without any negative effect to the performance of the vehicle.

2.4 Permanent Magnet (PM) Generator

Generator can be classified into the electrically excited (EE) machine and permanent magnet (PM) machine. The electrical energy generated by the generator basically follows Faraday's Law of induction. In this law stated that the induced electromotive force (EMF) in a close circuit is equal to the time rate of the magnetic flux through the circuit. There is a few type of permanent magnets generator topologies for small scale that can be used for this project such as axial flux generator, Toroidal flux generator and Radial flux generator (Ahmad & Amin, 2017; Amei, Takayasu, Ohji, & Sakui, 2002).

2.4.1 Axial Flux Generator

Axial flux permanent magnet (AFPM) generator has high efficiency compare to another two type of permanent magnets generator. This is because the filed excitation losses are eliminated, thus resulting in significant rotor loss reduction (Ahmad & Amin, 2017; Hosseini, Agha-Mirsalim, & Mirzaei, 2008).

2.4.2 Magnetic levitation

Magnetic levitation is used to nullify the weight of the rotor in the generator. By levitating the rotor, the mechanical contact between the rotor and surrounding mechanical parts can be avoided. To implement this method, two set of axially magnetized ring magnets are placed in such a way, where in a repelling state to each other. With repulsion of the two magnets, the weight of the hub and other rotating parts can be partially nullified because the center of gravity is not exactly located at the center of the rotor blade (Ahmad & Amin, 2017)

2.4.3 Design of Rotor

The material used for the rotor to improve the efficiency of the generator is non-magnetized material such as Teflon and Polyster (Kurt, Gör, & Demirtaş, 2014). To generate a strong magnetic field, two rotor plates are needed with the rotor poles in opposite arrangement. In order to create three phase output waveform, required a specific ratio between the number of permanent magnets on the rotor plate and number of stator coils. Figure 2.4.3 shows an example of rotor plate with the magnet arrangement (Ahmad & Amin, 2017; Hosseini et al., 2008; Kurt et al., 2014).

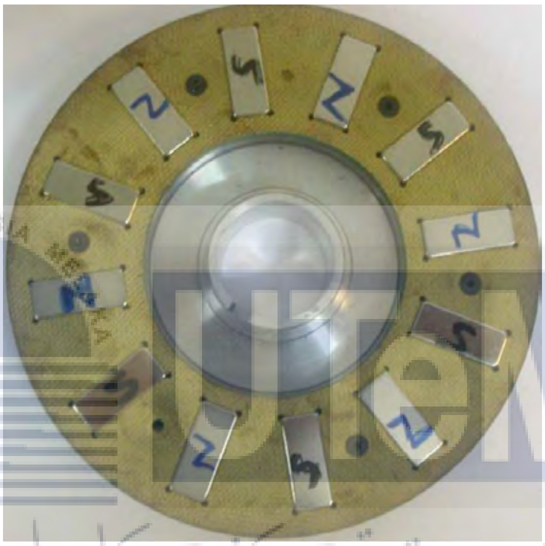


Figure 7 Rotor plate with magnet arrangement (Hosseini et al., 2008).

2.4.4 Design of Stator

In a generator system, coils are one of the important part to produce voltage. The higher the number of coils, the bigger the power output can produced (Hosseini et al., 2008; Kurt et al., 2014). Stator plate is used to hold the magnetic wire coils. To design stator plate, the right material should be selected. The best material for stator plate is from non-conducting and non-magnetic material (Ahmad & Amin, 2017). Next, the ironless stator also can eliminate the direct magnetic attraction between rotor and stators (Hosseini et al., 2008). In addition, coreless stator has high efficiency for distributed power generation system.

2.4.5 Three Phase Rectifier

Three phase rectifier has small voltage wave compared to single phase circuit and has three times more AC supply frequency. In order to create the three phase rectifier, six diodes are required as shown in Figure 2.4.4 to produce a smooth output from a three phase input (Ahmad & Amin, 2017; Li & Chen, 2009)

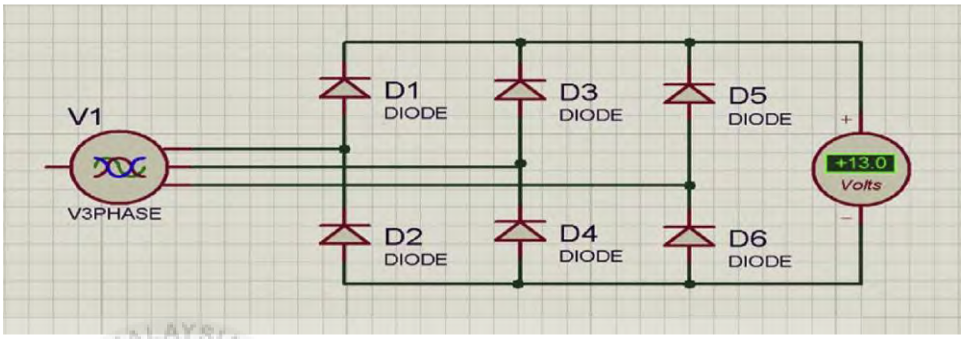


Figure 8 Three phase rectifier circuit
(Ahmad & Amin, 2017)

CHAPTER 3

METHODOLOGY

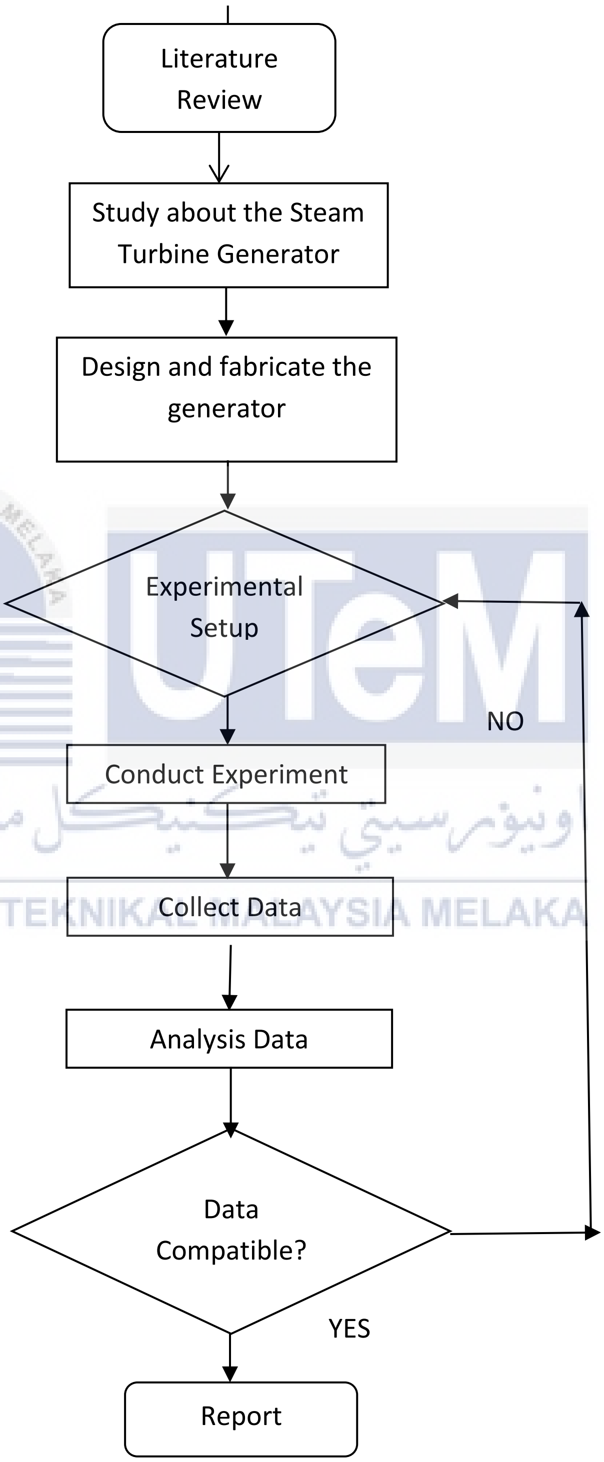
3.1 Introduction

In this chapter will discuss about the methods that being use in order to complete this project. Those methods are implemented during the period of the project to achieve the objectives based on the scope of the project as stated in Chapter 1. The method that being use as listed below:

i. Searching and collecting information regarding the steam turbine generator.
ii. Fabricating based on selected design
iii. Installing the generator and road testing on the car.
iv. Collecting data regarding speed, temperature and power output generated by the generator.
v. Identified problem, solution and make the improvement.

3.2 Methodology Progress Flow

The methodology of this study is summarized in the flow chart as shown below.



3.3 Design and Fabrication Process

In this process, the main design for the generator was selected as shown in Figure 3.7. This design was proposed in Journal of Design, Prototyping, and Analysis of a Low Cost Axial-Flux Coreless Permanent-Magnet Generator written by Seyed Mohsen Hosseini, Mojtaba Agha-Mirsalim, and Mehran Mirzaei.

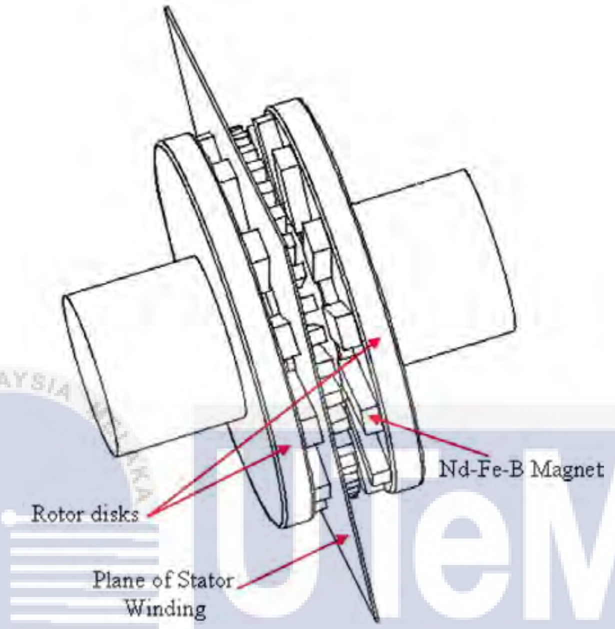


Figure 9 The main design of the generator
(Hosseini et al., 2008)

This design was chosen because of its flexibility where a lot of improvements and modifications can be implemented in order to fulfil the requirement to achieve the objective which is generate higher power output of electrical energy. Those are the number of permanent magnet used at rotor, the number of coils at the stator and many more. Other than that, this generator design also suitable to be installed in a small space area where as for this project, the generator will be installed at the small free space near to the engine of the experiment vehicle. Figure 3.3.2 show the position of the generator under the car hood.

Figure 10 The position of the generator under the car hood

(Herawan et al., 2015)

Before start the designation process, the design parameters were set for suitable dimension for the rotor and stator so that the generator will fit with the small space in the car hood. The dimensions are according to the number of magnet and coil that will be used. The higher the number of the magnet and coil used, the bigger the diameter for the rotor and stator as shown in Table 1.

Table 1: Design parameter for the generator

Components	**Features**
Diameter of rotor R1	100mm
Diameter of rotor R2	100mm
Diameter of Stator	100mm
Coil inner diameter	15mm
Coil outer diamater	20mm
Winding turns	100
Winding diameter	0.5mm
Magnet type	NdFeB
Magnet shape	Circular
Magnet diameter	30mm
Magnet thickness	3mm
Core material	Delrin
Air gap	3mm

3.3.1 Design Selection

After go through a few research and modification process, there are two final design, Design A and Design B of the generator were created as shown in Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, and Figure 14. From the those designs, Design B has been selected as the best design before continue the next process which is fabricating process.

Figure 11 Design of Rotor 1 for Design A

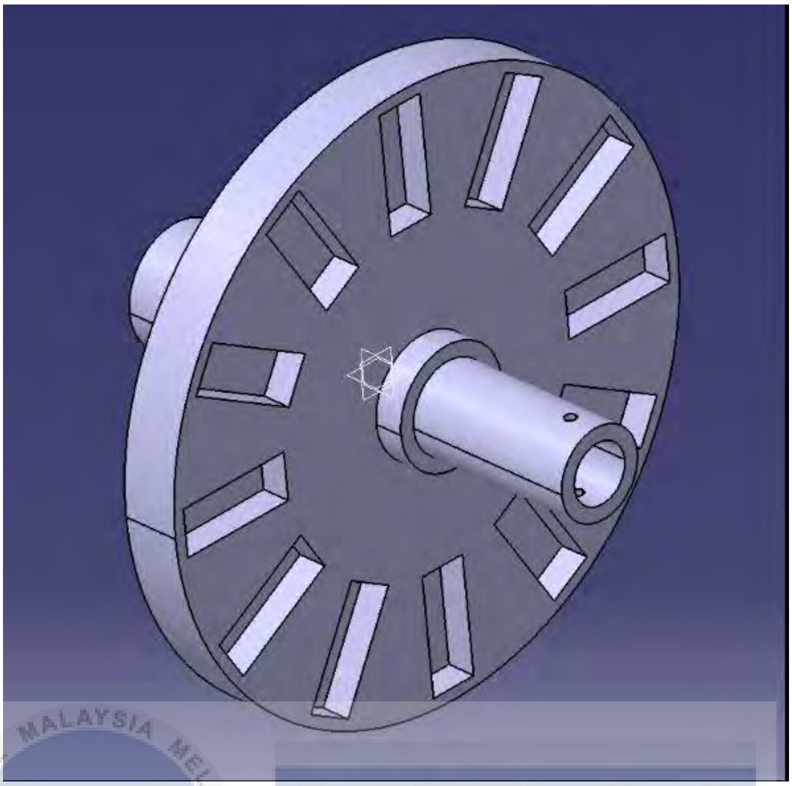


Figure 12 Design of Rotor 2 for Design A

Figure 13 Design of Stator for Design A

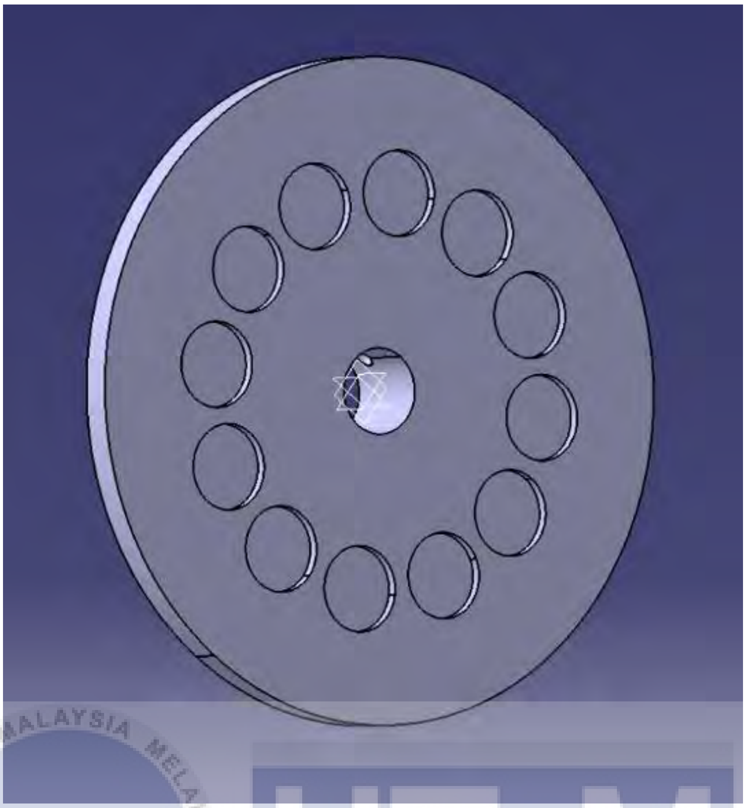


Figure 14 Design of Rotor 1 for Design B

Figure 15 Design of Rotor 2 for Design B

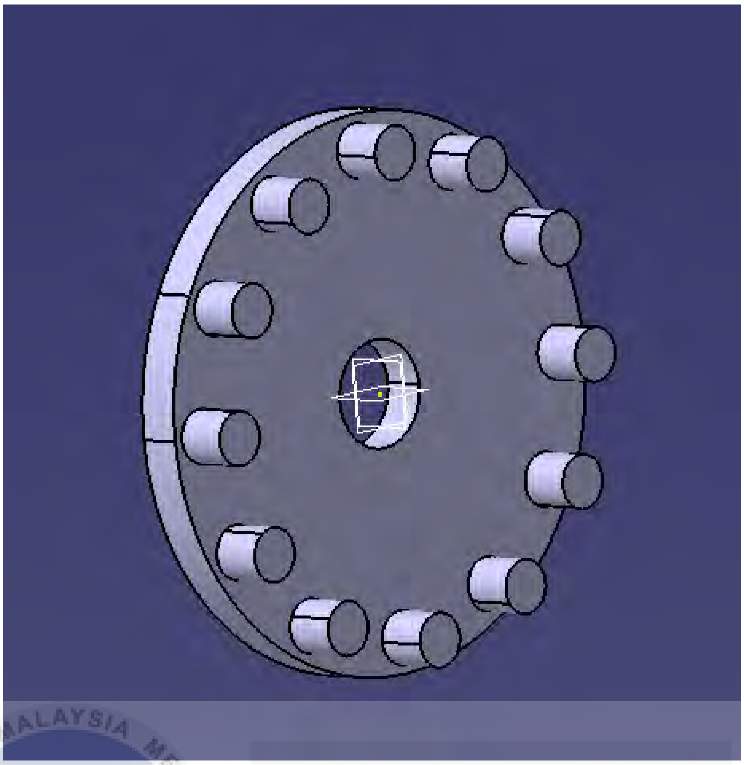


Figure 16 Design of Stator for Design B

3.3.2 Material Selection

For the next step was fabrication process. This process starts with material selection for the stator and rotor. The material should have high physical properties that can withstand the high speed of rotation of turbine and also the excessive heat from the engine. Derlrin was selected as the most suitable material for this project as shown in Figure 17.

Figure 17 shows the Derlin as the selected material

Delrin or Acetal Homopolymer is a crystalline plastic that has an excellent balance of properties that bridge that gap between metals and plastics Delrin possesses high tensile strength, creep resistance and toughness. It also exhibits low moisture absorption. Other than that, it is also chemically resistant to hydrocarbons, solvents and neutral chemical. The properties along with its fatigue endurance make Delrin ideal for many industrial applications. Delrin overall combination of physical, tribological and environmental properties make it ideal for many industrial wear and mechanical applications. Lastly, the most important is Delrin is a non-magnetic material which is does not distract the electromagnetism reaction between the magnet and the coils. Table 2 shows the detail information and Primary Specification of Delrin.

Table 2: Information and Primary Specification of Delrin

Property	ASTM Test Method	Units	Delrin® 150
Physical			
Density	D792	lbs/in^3	0.0513
Specific Gravity	D792	g/cc	1.42
Water Absorption, @ 24 hours	D570	%	0.25
Water Absorption, @ Saturation	D570	%	0.9
Mechanical			
Tensile Strength @ Yield	D638	psi	11,100
Tensile Modulus	D639	psi	450,000
Elongation @ Break	D638	%	25
Flexural Strength	D790	psi	11,500
Flexural Modulus	D790	psi	420,000
Compressive Strength	D695	psi	5,200
Izod Impact Strength	D256	ft-lbs/in	1.5
Rockwell Hardness	D785	M (R) Scale	M 94 (120)
Wear Factor Against Steel, 40 psi, 50 fpm	D3702	in^3/hr x 1/PV	55 x 10^{-10}
Static Coefficient of Friction	D3702		–
Dynamic Coefficient of Friction, 40 psi, 50 fpm	D3702		0.2
Thermal			
Heat Deflection Temperature @ 66 psi	D648	°F	336
Heat Deflection Temperature @ 264 psi	D648	°F	257
Coefficient of Linear Thermal Expansion	D696	in/in/°F	6.8 x 10^{-5}
Maximum Servicing Temperature, Intermittent		°F	300
Maximum Servicing Temperature, Long Term	UL746B	°F	185
Specific Heat		BTU/lb-°F	0.35
Thermal Conductivity			–
Melting Point	D2133	°F	347
Flammability	UL94		HB (1.47)
Electrical			
Volume Resistivity	D257	ohm-cm	10^{15}
Dielectric Strength	D149	V/mil	500
Dielectric Constant, @ 60 Hz, 50% RH	D150		3.7
Dielectric Constant, @ 1 MHz	D150		3.7
Dissipation Factor, @ 60 HZ	D150		0.005

3.3.3 Stator, Rotor and Coil Winding

After the material of the generator had been selected, then rotor and stator start to be fabricated. These two main parts of generator was fabricated by using Conventional Lathe Machine as shown in Figure 18.

Figure 18 Conventional Lathe Machine used to fabricate the stator and rotor.

Next step, the winding process of coils. There are six winded coils used for this generator. Those coils winded manually used a tool call as winder. Figure 19 shows the winder that created from the PVC pipe, 4 inches screw with diameter 0.5 mm and a roller. This tool used to ease the winding process of the coils and also produces a neat arrangement of coils. For this generator, the copper wire that was used to make the winded coils is 0.5 mm diameter with internal diameter of the winded coil is 20 mm. The copper wire was winded with 100 turns to produce a complete winded coil. The height of the winded coils was set to 25 mm as the thickness of the stator is 25 mm. Figure 20 shows a complete winded coil before install to the stator.

Figure 19 Coils winder

Figure 20 A complete winded coils

Those six winded coil had been installed in the stator after completed the winding process. During the installation process, each coil should be placed in the stator with the same direction of coil turns. Figure 21 shows the position of the coils in the stator.

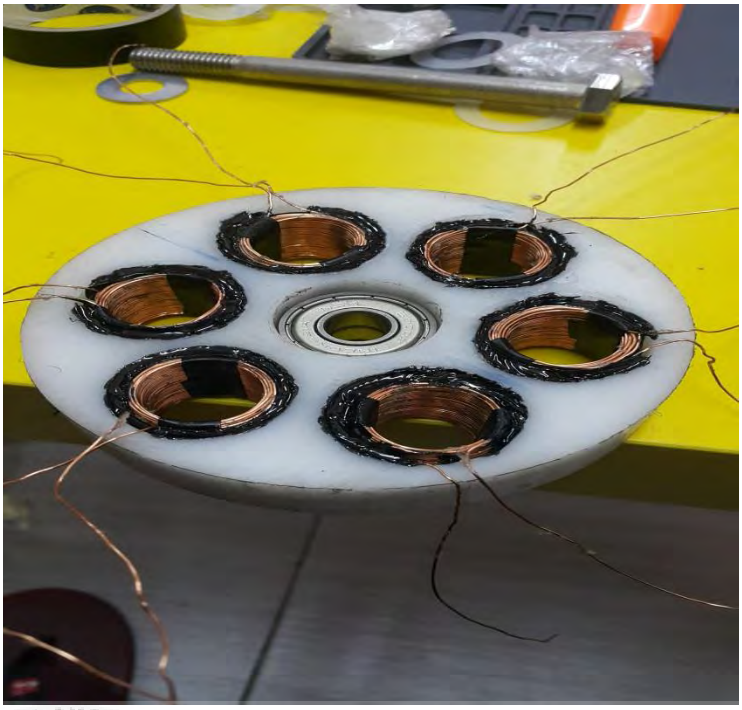


Figure 21 shown the position the coils

From above figure, a pair of ball bearing with internal and external diameter 10mm and 26 mm had been installed at the centre of the stator. These two ball bearings used to produce a less friction of rotation of the rotor. The six coils were sealed with an epoxy to fix then in their position when the rotor is rotating. Figure 22 shows the type of epoxy used.

Figure 22 shown the epoxy used to seal the coils

Next, the fabrication process continued with wiring setup to connect each coil to become a three phase power generator. Figure 23 shows how those six coils divided into three pairs to create 3 phase generator.

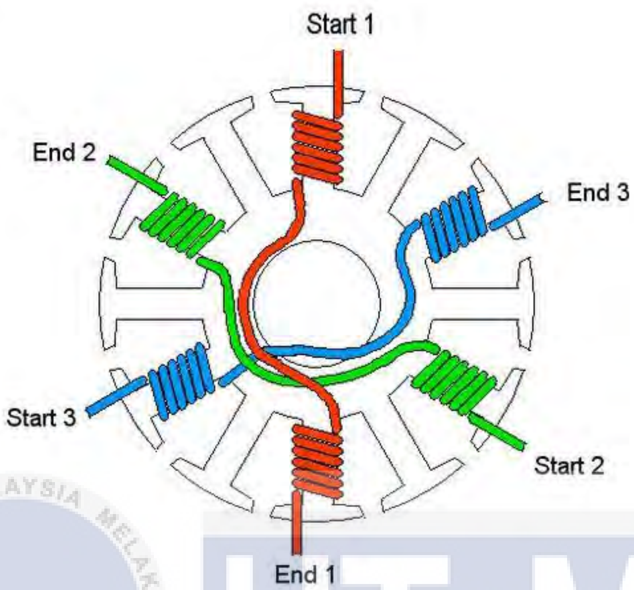


Figure 23 shows the coils divided into three part

Each pairs of the coils connected by series which means that the beginning of the Coil 1 will connected with end of Coil 4, Coil 2 with Coil 5, and Coil 3 with Coil 6. The end of coil for each pairs, End 1, End , and End 3 were connected together to create a neutral output, while Start 1, Start 2, and Start 3 for each pair became life output for three phase generator. Figure 24 shows the three life outputs of the generator as marked with red circle while neutral output as marked with blue circle.

Figure 24 shows the life and neutral output of generator

Then, the process continued with the fabrication of rotor. Rotor was from Delrin material and fabricated by using Conventional Lathe Machine. Rotor builds with eight slots for 2mm permanent magnets. The diameter of rotor was same with the stator which is 100 mm while the thickness of rotor was set to 5 mm. In the rotor fabrication process, the thickness was reduced as much as can in order to produce a light weight of rotor since the rotor weight can influence the rotation speed of rotor. The lighter the weight of rotor, the higher the speed of rotation of rotor can produced. From figure 25, there are eight permanent magnet were attached with rotor by using epoxy.

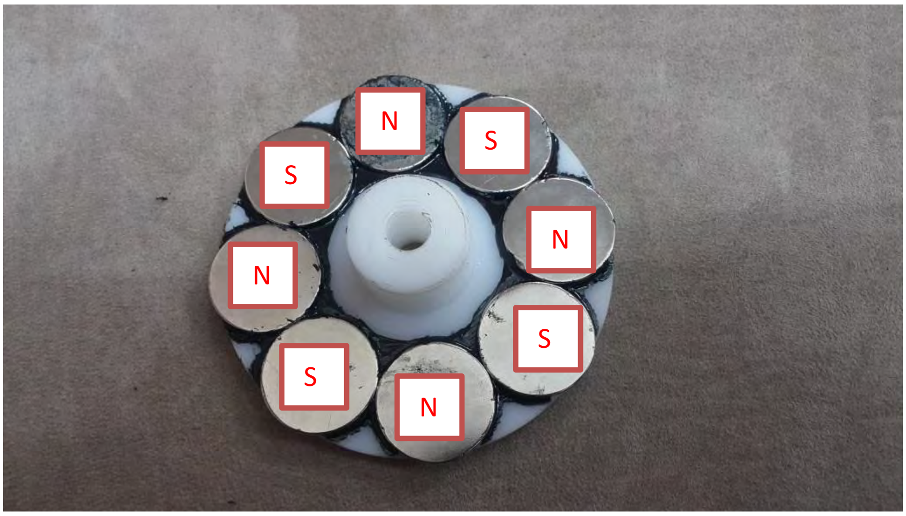


Figure 25 shows the sequences of magnet position

The arrangement of the magnet position must be alternating between North and South poles. The number of magnet depends on the diameter of rotor and it does not matter how many magnet that would be used, as long as the number is even, it is acceptable. For this project, the number of magnet used is eight with 30 mm diameter for each magnet. The rotor does not complete without a shaft. The shaft of rotor is made from a 60 mm long of stainless steel screw with 10 mm of diameter. The shaft must come from a non- magnetic material to make sure there is no other thing that can interrupt the electromagnetic forced produced by the generator. Figure 26 shows the process of fabricating the shaft to reduce the diameter at the end of the screw to become 8 mm. There is about 20 mm long of the screw have been reduced to fit with the diameter of the coupling aluminium as shown Figure 27. The coupling aluminium used to transfer the circular motion from the turbine to the rotor.

Figure 26 Convential Lathe Machine used in the process of fabricating the shaft

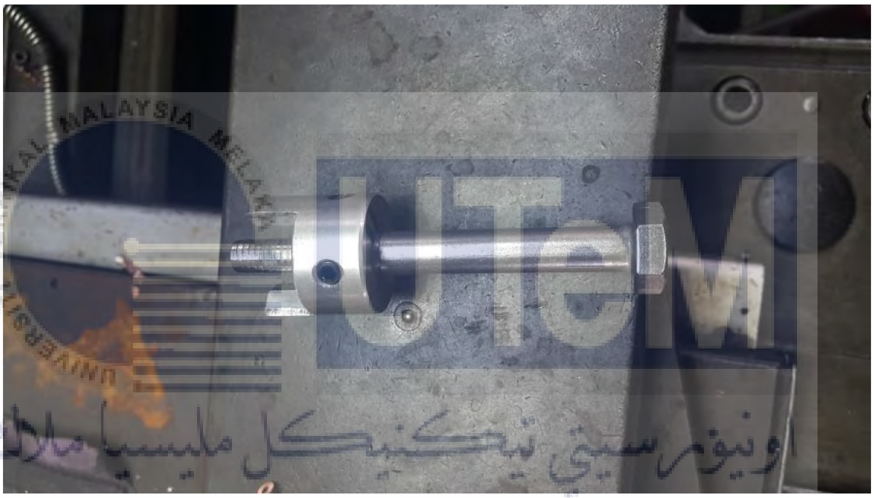


Figure 27 Coupling fit with shaft

Lastly, the final step of fabrication process of generator was converting the three phase AC voltage into DC voltage. To convert that AC output, the 3 phase diode bridge rectifier was used as mention in Chapter 2. To create that diode bridge rectifier, there were six 10 amp diodes used as shown in Figure 28.

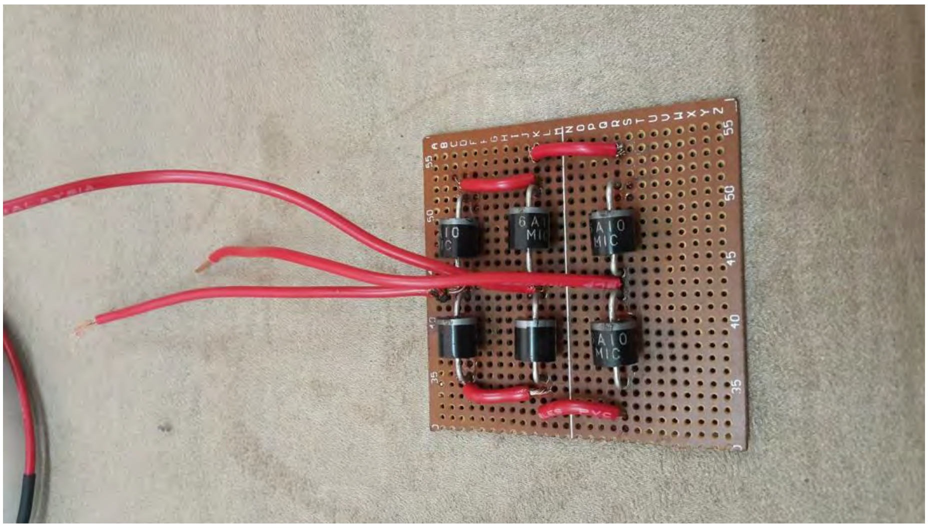


Figure 28 shows the 3 phase diode bridge rectifier

3.4 Experimental Setup

After the generator successfully fabricated, the next process is install that generator at the experimental vehicle. In this project, the generator will be installed on a Toyota vehicle which has 1.6 litre in-line four-cylinder gasoline. The specification of the engine as describe in Table 3.

Table 3: Test vehicle engine specification (Herawan et al., 2015)

Type of Components	Specifications
Valve train	DOHC 16 valves
Fuel System	Multi point fuel injection
Displacement	1587 cc (in line)
Compression ration	9.4.1
Bore	81mm
Stroke	77mm
Power	112Hp @ 600 rpm
Torque	131Nm @ 4800 rpm

Figure 29 shows the actual figure of the generator after install to the car. During the installation process, it is quite difficult to centralize the position of the generator with the turbine because of the small free space in the car hood.

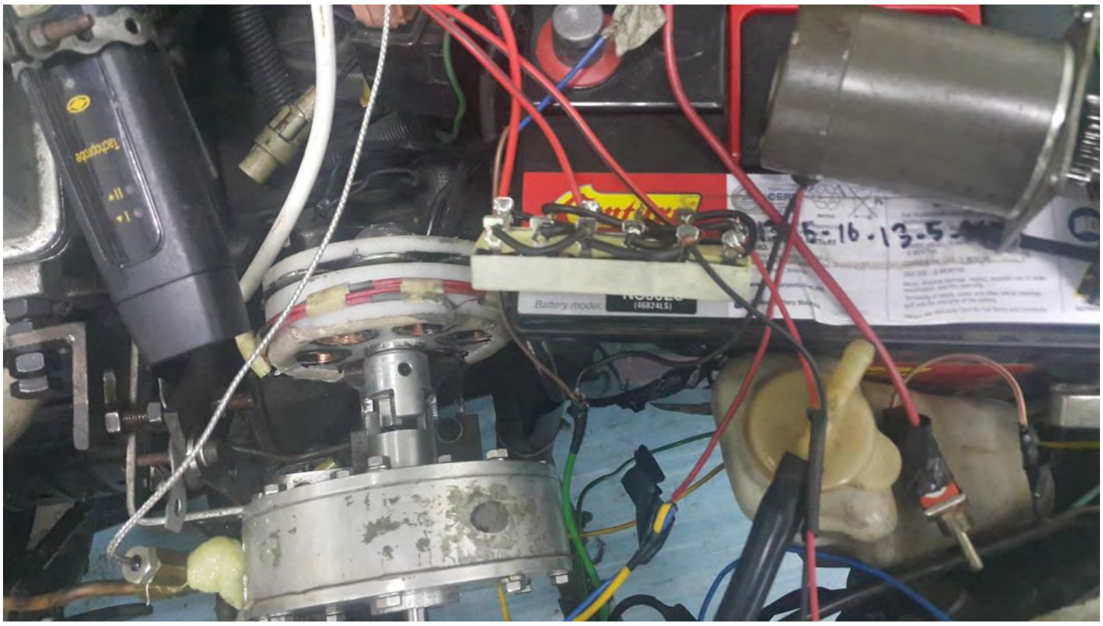


Figure 29 shows the position of the generator after the installation process.

To fix the position of the generator with the turbine, a holder was created. This holder fabricated by using Conventional Milling Machine as shown in Figure 30 and Figure 31.

Figure 30 shows the holder of the generator during the fabricating process

Figure 31 shows the holder after install at the generator

This project was planned to test the generator after installed in the car. The turbine will rotate the generator and the data will collected by using Thermocouple Data Logger. Unfortunately, the Thermocouple Data Logger that used to collect the data for this experiment was fault to function due to the crack on the LCD during the previous test. So, the plan was changed and the generator had been test externally. An electrical motor was used to replace the turbine to rotate the generator and the data was collected manually. Since there is a problem with the data collector device, the data collected by using the multimeter and tachometer. Multimeter used to collect the voltage output generated by the generator while tachometer was used to measure the rotation per minute (rpm) of the generator.

Figure 32 shows the position of the generator after installed at the motor. The generator was rotated by the motor at several rotations from 600 rpm, 1200 rpm, 1800 rpm, 2400 rpm, 3000 rpm, 3600 rpm, 4200 rpm, 4800 rpm, 5400 rpm, 6000 rpm, 6600 rpm, and 7200 rpm. Those rotations per minutes were measured by using Tachometer as shown in Figure 33.

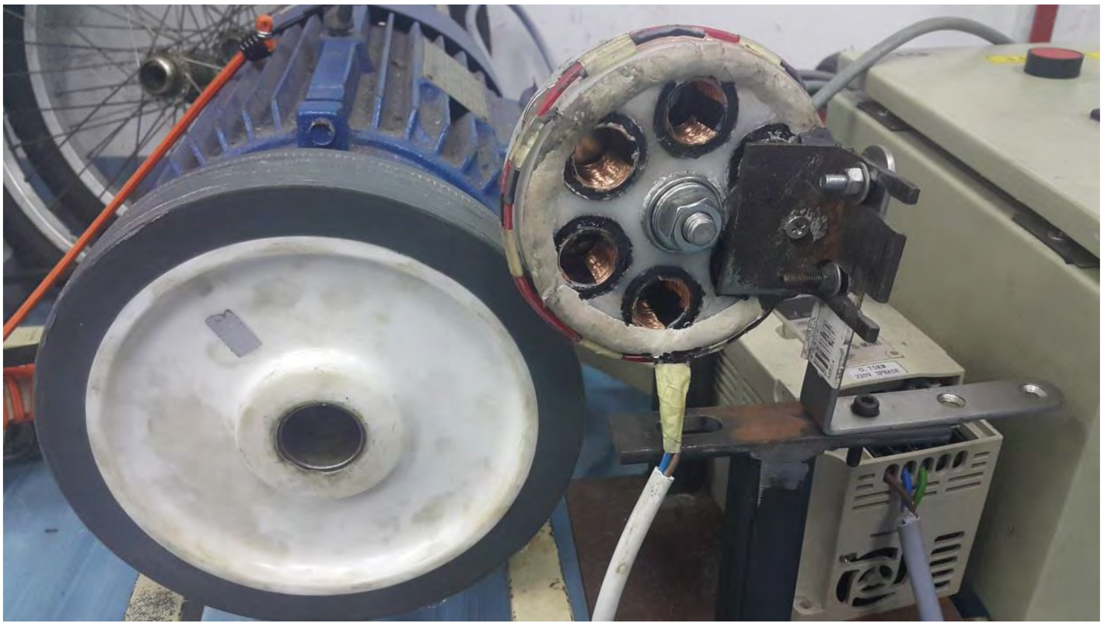


Figure 32 shows the position of the generator installed at the motor

Figure 33 shows Tachometer used to measure the rotation of the generator

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULT

Table 4: Results for the Generator 1

	Rotation per Minutes (rpm)	**Voltage Output**
1	600	2.31
2	1200	2.91
3	1800	3.62
4	2400	8.67
5	3000	11.32
6	3600	13.41
7	4200	15.64
8	4800	17.54
9	5400	19.77
10	6000	22.23
11	6600	24.66
12	7200	26.53

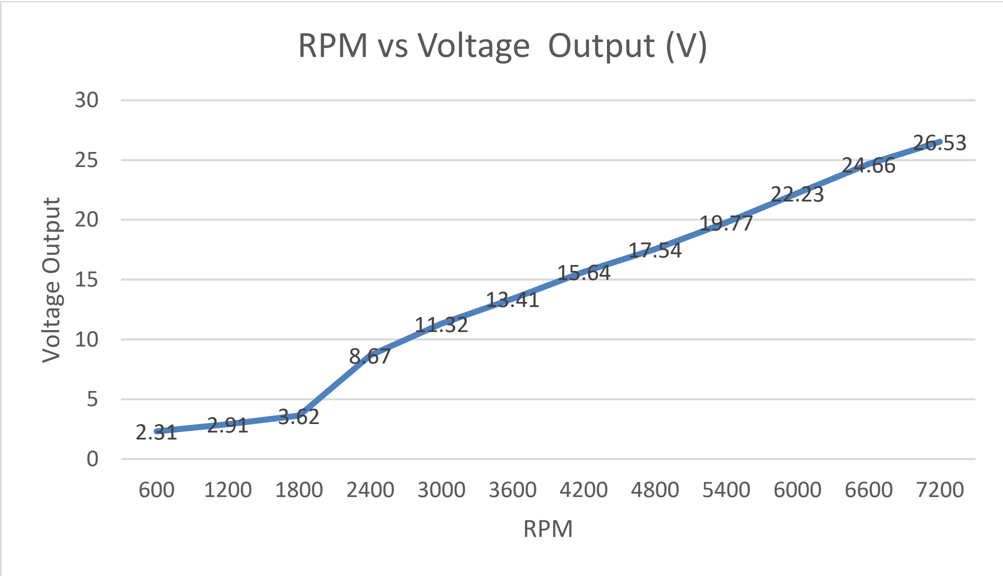


Figure 34 Graph RPM vs Voltage Output for Generator 1

Table 5: Result for the Generator 2

	Rotation per Minutes (rpm)	Voltage Output
1	600	11.89
2	1200	14.18
3	1800	19.79
4	2400	24.21
5	3000	28.53
6	3600	32.31
7	4200	36.52
8	4800	38.96
9	5400	40.86
10	6000	42.37
11	6600	43.82
12	7200	45.58

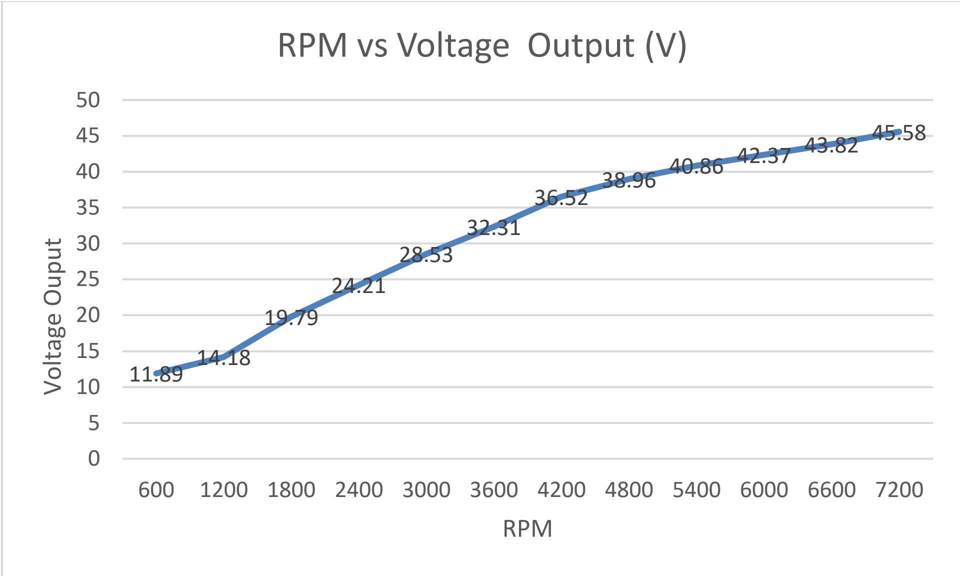


Figure 35 Graph RPM vs Voltage Output for Generator 2

4.2 DISCUSSION

Figure 34 and 35 shows the graph between the speed of the generator in rotation per minute (rpm) with output voltage generated by two generators which are the previous generator and the new fabricated generator. The previous generator is label as Generator 1 while the new fabricated generator labelled as Generator 2. Table 4 and 5 show the result of both generators' rotation per minute and voltage output that have been collected

Those data have been recorded by using Multimeter and Tachometer. The Tachometer was connected to the Multimeter during collecting the rotation speed of the motor which is 1 volts is equal to 1000 rpm. Both generator rotated by using the same motor. The trends of the graphs for both generators are quite same, which is when the speed of the motor increase, the output voltage produced by the generators also increases. The first data take when the rotation of the motor reached at the speed 600 rpm. At this speed, Generator 1 produced 2.31 volt while another generator, Generator 2 has produced 11.89 volt. The maximum speed the motor can achieved is about 7200 rpm. So that, for this experiment the optimum output voltage produced by both generator is at the speed of the motor at 7200 rpm. The optimum voltage produced by Generator is 1 26.53 volt while for Generator 2 is 45.58 volt.

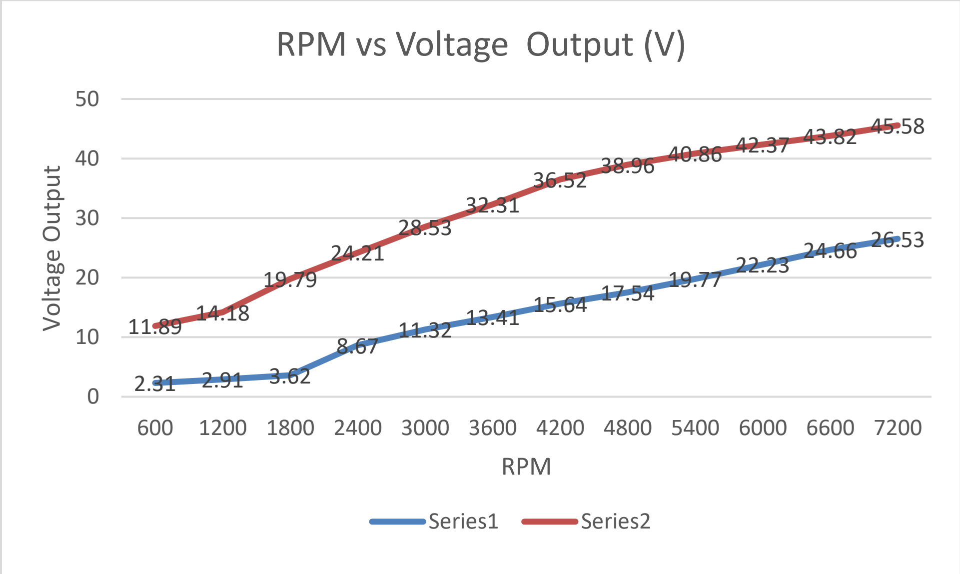


Figure 36 Graph RPM vs Voltage Output for Generator 1 and Generator 2

Based on the results obtained, Generator 2 which is the new fabricated generator for this project produce more output voltage compare to Generator 1 which is from the previous experiment as shown in Figure 36. The new generator considered more efficient since the voltage output generated is higher compare to another generator. There are several factors that can affect the efficiency and output voltage produced by the generator for this project. One of them is the number of turns of the coils. In this project, based on the a few research from the paper the number of turns used during the process of coils winding is 100 turns. The higher the number of turns for the coils, the higher the output voltage will be produced. Other than that, the diameters of the copper wire used for the fabrication of the coils also influence the output voltage produce. The thicker the diameter of the copper wire, the higher the output voltage can be generated by the generator. In this case, the diameter copper wire used is 0.5 mm.

Furthermore, the other factor that can affect the efficiency of the generator is the force of electromagnetic force produced by the magnet. The higher the electromagnetic force produces by the magnet, the higher the output voltage can be produced by the generator. There are two ways to increase that electromagnetic force. One is by increasing the size or diameter of the magnet used in this project. The second one is by increase the number of the magnet attached at the rotor. In this case, the number of the magnet only can be increase if use a pair of rotor because the diameter of the rotor too small to fit more than 8 magnets for each. Lastly, the inner diameter of the winded coils also can affect the efficiency of the generator. Winded coils with larger inner diameter normally can produce larger voltage output compare to the smaller one. For this project, the inner diameter of the winded coils used is 15mm.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The result and analysis of the experiment has been carried out at Makmal Penghawa Dingin in Fasa B, Utem. Based from the project, the generator has successfully fabricated and fully functioning which is can produce output voltage. As predicted, the output voltage produced by the fabricated Generator 2 is higher compare to Generator 1 and this can be considered as more efficient.

This is because of the a few factors that can affect and influenced the output result such as the number of turns of coils, the diameter of copper wire used to fabricate the coils and the electromagnetic force produced by the magnet. The output voltage produced by the generator can be increase by increasing the number of coils, the diameter of the copper wire and the number or diameter of the magnets.

In other hand, this experiment has the limit of the motor speed used to rotate both generators. Since the motor can rotate both generator at 7200 rpm only, the data collected also quite inaccurate in order to achieve an optimum output voltage produced and the limits of the fabricated generator. As the result, the highest output voltage produce by the fabricated generator is 45.58 volt at 7200 rpm of rotation speed.

As the conclusion, the design for this generator is considered as the best and compatible design for the steam turbine generator since the efficiency and amount of the output voltage generated by the generator was increasing. Last but not least, this project is considered successful due the achievement of the all objectives as mention in Chapter 1.

5.2 RECOMMENDATION

The generator has been successfully fabricated with fully functioning with the output voltage produce by the generator is more efficient. There are a few action must be done in order to enhance this system to become even well than before. Firstly, the size of the generator is quite small to locate more coils and permanent magnet. This size is related with the free space in the car hood. Moreover, the duration of this project is quite short. This project needs to take more time in order to find the number of turns of coils, diameter of the copper wire and the number of the magnet used that are suitable to generated higher amount of output voltage. To get the best result, try and error experiment must be carry on and this might take a long duration. Increasing the duration might help to get better result. Lastly, the cost for this project is quite high. To carry on try and error experiment, a high number of costs needed.

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