DESIGN AND DEVELOPMENT A SMALL STIRLING ENGINE

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A report submitted in fulfillment of the requirements
for the award of Bachelor of Mechanical Engineering.

Faculty of Mechanical Engineering
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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Design and Development a Small Stirling Engine" is written by Nurul Huda Binti Baso. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering.I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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Examiner   Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this report and in my opinion this project is sufficient in terms of scope and quality of this thesis is qualifies for the award of Bachelor of Mechanical Engineering.

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Date : 5th JUNE 2012

STUDENT'S DECLARATION

I hereby declare that the work in this report entitled *"Design and Development a Small Stirling Engine"* is the result of my own project except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of any other degree.

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DEDICATION

I specially dedicate to my family, my supervisor, my best friend and all my friends for their constant support and encouragement

ACKNOWLEDGEMENTS

Alhamdulillah, thank you Allah for giving me the world worth life. Without his mighty I won't be able to finish this project on time. Secondly, thanks to my supervisor, Mr Lee Giok Chui SMP.KMN for his superb guidance and advice. I sincerely thanks to technical staff Mr. Aziha Bin Abdul Aziz and Mr. Mohd Adib Bin Mohd Amin for their opinion and suggestion.

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It is also a pleasure to thank my entire classmate for all of their ideas, comments and moral support in completing my final project. Indeed, I could never adequately express my indebtedness to all of them. Thank you.

ABSTRACT

A stirling engine is a heat engine operating by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such as net conversion of heat energy to mechanical work. The Stirling engine was noted for its high efficiency compared to steam engines, quiet operation, and the ease with which it can use almost any heat source. The purpose of the project, are to design and fabricate the stirling engine. In this project, all the components were fabricating using milling machine, cutter, lathe machine, and CNC machine. Besides that, all the components will be assembled and the performance of stirling engine will be analyzed. Schmidt Analysis of Ideal Isothermal equation were use to find the performance of stirling engine in watt. The fin at cold cylinder will be analyzed using fins heat transfer equation.

ABSTRAK

Enjin stirling adalah kitaran operasi enjin oleh haba mampatan dan pengembangan oleh udara atau gas pada tahap suhu tenaga bersih kepada kerja mekanik. Enjin Stirling terkenal dengan kecekapan yang tinggi berbanding dengan enjin wap, operasi yang senyap dan mudah yang boleh menggunakan hampir mana-mana sumber haba. Tujuan projek ini, adalah untuk mereka bentuk dan memasang siap enjin stirling. Dalam projek ini, semua komponen telah direkabentuk menggunakan mesin milling, mesin larik dan mesin CNC. Selain itu, semua komponen akan dipasang dan prestasi enjin stirling akan dianalisis. Analisis Schmidt persamaan Isothermal telah digunakan untuk mencari prestasi stirling enjin dalam watt. Sirip pada silinder sejuk akan dianalisis dengan menggunakan sirip persamaan pemindahan haba.

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CHAPTER 1

PROJECT FRAMEWORK

1.1 Introduction

Stirling engines are a category of engine, just like diesel engines. They are a closed-cycle engine, which means that air or other gas such as helium is used over and over again inside the engine. Stirling engines can be “regenerative.” This means that some of the heat used to expand the air in one cycle can be used again to expand the air in the next cycle. Stirling engines do this by moving the air across another material called a regenerator. When the hot air in a Stirling engine flows over the cool regenerator, some of the heat from the air flows into the regenerator, heating it up. This pre-cools the air before it moves to the cold side of the engine, where it will reject more of its heat and complete the cycle.

This project starts with the basic information of stirling engine. Software SolidWorks2011 is extensively used in order to design the 3D and orthographic drawings. Then, all part was fabricated and assembles.

1.2 Project Background

This project begins with an overview all types of stirling engine. To design 3D and orthographic drawings of stirling engine software SolidWorks 2011 is being used. From that, all components of stirling engine had been shown and fabricate. To assemble all components of stirling engine all part will fabricate and output of stirling engine will perform.

1.3 Problem Statement

In the recent ‘green-energy’ movement the stirling cycle has received renewed interest in the area of power generation, and it is the intention to help raise awareness and promote renewable energies by demonstrating the potential of the stirling engine. Stirling engine are known for having a high thermodynamic efficiency. Ideally, a stirling cycle engine can be designed to approximate the theoretical carnot cycle engine.

1.4 Project Objective

The main objectives of this project are:

1. To design the stirling engine.
2. To fabricate the stirling engine.
3. To determine the performance of stirling engine.

1.5 Scope of Project

This project will focus on:

1. Gamma type stirling engine.
2. Reviewing the history, other research and study relevance to the title.
3. Design the small stirling engine.
4. Select suitable material for each components and parts.

5. Fabricate the small stirling engine using suitable process, concept and suitable machine.

1.6 Project Report Organization

This project is organized into five chapters where:

1. Chapter 1 includes the project framework.

2. Chapter 2 reviews on the historical,

3. Chapter 3 presents on the methodology of the project. This chapter reviews on the machines that were used such as Miling Machine, Cutter, Lathe Machine, and CNC machine. Besides that, SolidWorks2011 was discussed.

4. Chapter 4 focuses on result and discussion. In this chapter the performance and heat transfer of the stirling engine will been reviewed. All the obtaining result or output is discussed too.

5. Chapter 5 will summarize all the obtaining results. Recommendation for further work is also given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a history of stirling engine and process flow in all its types. Besides, an overview of flywheel design principles is also presented.

2.2 History of Stirling Engine

The Stirling engine was invented by Robert Stirling, a Scottish minister, in 1816. The early Stirling engine had a history of good service and long life (up to 20 years). It was used as a relatively low-power water-pumping engine from the middle of the nineteenth century to about 1920, when the internal combustion engine and the electric motor replaced it. The hot-air engine was known for its ease of operation and its ability to use any burnable material as fuel. It's safe, quiet, moderately efficient operation and its durability and low maintenance requirements. It was very large for its small power output with a high purchase cost. Nevertheless, its low operating cost usually justified choosing it over the steam engine the only alternative at the time which burned much more fuel for the same power and demanded constant attention to avoid dangerous explosions or other failures.

This situation changed in 1980, when the U.S. Agency for International Development (USAID) funded the development of a simple Stirling engine specifically intended for manufacture and use in developing countries. The engine was designed, built, tested, and delivered to Bangladesh, and copies of it were built and put into operation there.

This demonstrated the Possibility of the engine's manufacture in simple machine shops of the type found in many regions of Africa, Asia, and Latin America.

2.3 Stirling Engine Cycle

The ideal Stirling cycle is represented in Figure 2.1 and consists of four processes which combine to form a closed cycle: two isothermal and two isochoric processes. The processes are shown on both a pressure volume (P-v) diagram and a temperature-entropy (T-s) diagram as per Figure 2.1. The area under the process path of the P-v diagram is the work and the area under the process path of the T-s diagram is the heat. Depending on the direction of integration the work and heat will either be added or subtracted from the system. Work is produced by the cycle only during the isothermal processes. To facilitate the exchange of work to and from the system a flywheel must be integrated into the design which serves as an energy exchange hub or storage device. Heat must be transferred during all processes. See Figure 2.1 for a description of the 4 processes of the ideal Stirling cycle (Borgnakke et al., 2003).

Process 1-2 : Isothermal compression

- Heat rejection to low temperature heat sink
- $_1Q_2$ = area *1-2-b-a* on T-s diagram
- Work is done on the working fluid (energy exchange from flywheel)
- $_1W_2$ = area *1-2-b-a* on P-v diagram

Process 2-3 : Isochoric heat addition

- Heat addition (energy exchange from regenerator)
- $_2Q_3$ = area *2-3-c-b* on T-s diagram
- No work is done
- $_2W_3 = 0$

Process 3-4 : Isothermal expansion

- Heat addition from high temperature heat sink
- $_3Q_4$ = area *3-4-d-c* on T-s diagram
- Work is done by the working fluid (energy exchange to flywheel)
- $_3W_4$ = area *3-4-a-b* on P-v diagram

Process 4-1 : Isochoric heat rejection

- Heat rejection (energy exchange to regenerator)
- $_4Q_1$ = area *1-4-d-a* on T-s diagram
- No work is done
- $_4W_1 = 0$

Figure 2.1: Ideal Stirling Cycle Process Summary

Source: Ideal Stirling cycle, Borgnakke et al. (2003)

The nett work produced by the closed ideal Stirling cycle is represented by the area 1-2-3-4 on the P-v diagram. From the first law of thermodynamics the net work output must equal the net heat input represented by the area 1-2-3-4 on the T-s diagram. The Stirling cycle can best approximate the Carnot cycle out of all gas powered engine cycles by integrating a regenerator into the design. The regenerator can be used to take heat from the working gas in process 4-1 and return the heat in process 2-3. Recall that the Carnot cycle represents the maximum theoretical efficiency of a thermodynamic cycle. Cycle efficiency is of prime importance for a solar powered engine for reasons that the size of the solar collector can be reduced and thus the cost to power output ratio can be decreased.

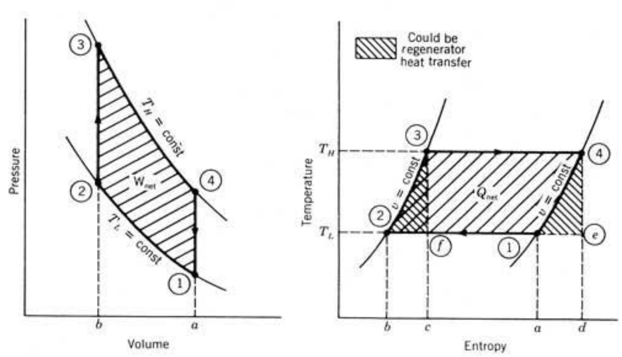

Figure 2.1: Ideal Stirling Cycle P-v and T-s Diagrams

Source: Sesusa.org.DrIz.isothermal

The real Stirling engine cycle is represented in Figure 3 below. As can be seen there is work being done during processes 2-3 and 4-1 unlike the prediction of zero work in the ideal cycle. One of the major causes for inefficiency of the real Stirling cycle involves the regenerator. The addition of a regenerator adds friction to the flow of the working gas. In order for the real cycle to approximate the Carnot cycle the regenerator would have to reach the temperature of the high temperature thermal sink so that $T_R=T_H$. A measure of the regenerator effectiveness is given by Equation 1, with the value of e=1 being ideal.

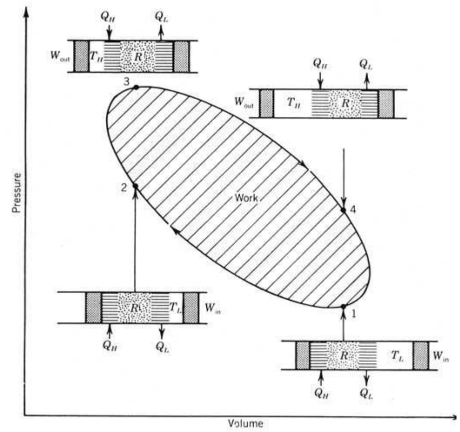

Figure 2.2: Real Stirling Cycle P-v Diagram Approximation

Source: Sesusa.org.DrIz.isothermal

$$e = \frac{T_R - T_L}{T_H - T_L} \tag{2.1}$$

T_H = Temperature of high thermal sink

T_L = Temperature of low thermal sink

T_R = Mass averaged gas temperature of regenerator leaving during heating

The Carnot efficiency is denoted by Equation (2) and the real cycle efficiency with regenerator is denoted by Equation (3). Though regeneration is not required for a Stirling cycle, its inclusion can help improve the efficiency if applied properly. Note how the regenerator efficiency does not tend to zero as the regenerator effectiveness tends to zero.

$$\eta\ carnot = 1 - \frac{T_L}{T_H} \tag{2.2}$$

$$\eta\ regenerator = \frac{T_H - T_L}{T_H + \left[\frac{1-e}{\frac{C_p}{C_p} - 1}\right]\left[(T_H - T_L)/\ln(\frac{v_1}{v_2})\right]} \tag{2.3}$$

$$\eta\ regenerator < \eta\ carnot \tag{2.4}$$

2.4 Types of Stirling Engine

2.4.1 The Alpha Types

This alpha type contains two cylinders which are normally arranged in an angle of 90 degrees. Because of this, it is also referred to as V-type. But there can be models found where the two pistons are coaxial. Normally one end is heated and the other end is cooled, but there are also versions where the gas gets heated in the middle of the connecting piece of the two cylinders. It does not have a displacer piston, but a compressor piston. One way to realize this type is to heat next to the working piston and to cool the volume with the compressor piston. The connection part of the two cylinders can contain the regenerator that shown in **Figure 2.3** below.

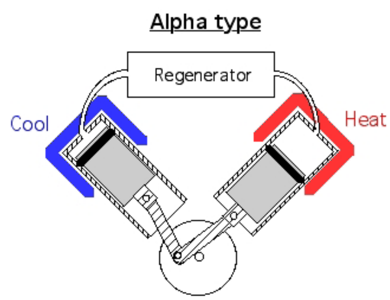

Figure 2.3: The Alpha Type

Source: Ohio.edu.stirlingengines.alpha

The Generator For Alpha Type Is Illustrated By The Chamber Containing The Hatch Lines.

1. **Figure 2.4** Expansion: At this point, the most of the gas in the system is at the hot piston cylinder. The gas heats and expands, pushing the hot piston down, and flowing through the pipe into the cold cylinder, pushing it down as well.

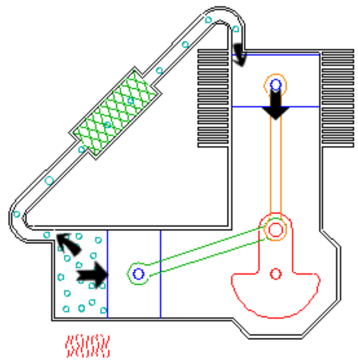

Figure 2.4: The Alpha Type Expansion

Source: Ohio.edu.stirlingengines.alpha

2. **Figure 2.5** Transfer: At this point, the gas has expanded. Most of the gas is still in the hot cylinder. The crankshaft continues to turn the next 90°, transferring the bulk of the gas to the cold piston cylinder. As it does so, it pushes most of the fluid through the heat exchanger and into the cold piston cylinder.

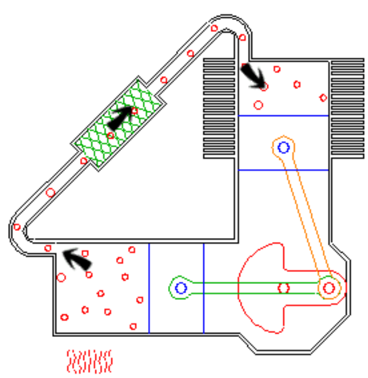

Figure 2.5: The Alpha Type Transfer

Source: Ohio.edu.stirlingengines.alpha

3. **Figure 2.6** Contraction: Now the majority of the expanded gas is shifted to the cool cylinder. It cools and contracts, drawing both pistons up.

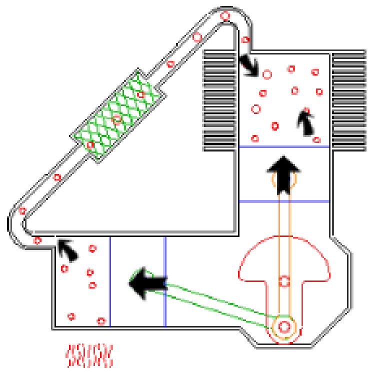

Figure 2.6: The Alpha Type Contraction

Source: Ohio.edu.stirlingengines.alpha

4. **Figure 2.7** Transfer: The fluid is cooled and now crankshaft turns another 90°. The gas is therefore pumped back, through the heat exchanger, into the hot piston cylinder. Once in this, it is heated and we go back to the first step.

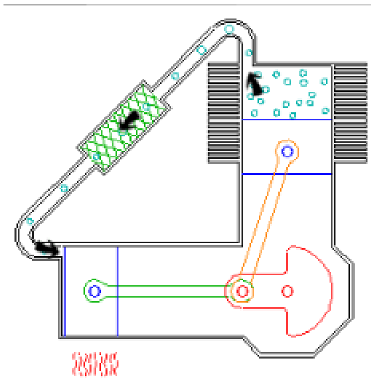

Figure 2.7: The 2nd Alpha Type Transfer

Source: Ohio.edu.stirlingengines.alpha

5. The alpha engine is conceptually the simplest stirling engine configuration, however the disadvantages that both pistons need to have seals to contain the working gas. This type of engine has a very high power to volume ratio but has technical problems due to the usually high temperature of the “hot” piston and its seals.

2.4.2 The Beta Type

The beta type stirling in **Figure 2.8** engine has only a single power piston and a displacer, which regulates if the gas gets heated up or cooled down. A beta stirling has a single power piston arranged within the same cylinder on the same shaft as a displacer piston. The displacer piston is a loose fit and does not extract any power from the expanding gas but only serves to shuttle the working gas from the hot heat exchanger to the cold exchanger.

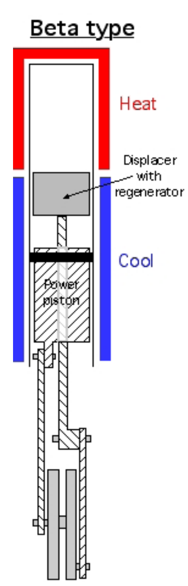

Figure 2.8: The Beta Type

Source: Ohio.edu.stirlingengines.beta.

The Generator Of Beta Type Is Illustrated By The Chamber Containing The Hatch Lines.

1. **Figure 2.9** Expansion: At this point, most of the gas in the system is at the heated end of the cylinder. The gas heats and expands driving the power piston outward.

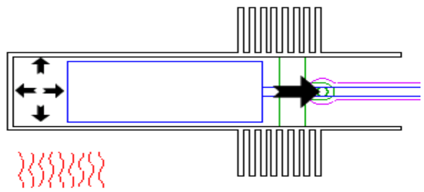

Figure 2.9: The Beta Type Expansion

Source: Ohio.edu.stirlingengines.beta

2. **Figure 2.10** Transfer: At this point, the gas has expanded. Most of the gas is still located in the hot end of the cylinder. Flywheel momentum carries the crankshaft the next quarter turn. As the crank goes round, the bulk of the gas is transferred around the displacer to the cool end of the cylinder, driving more fluid into the cooled end of the cylinder.

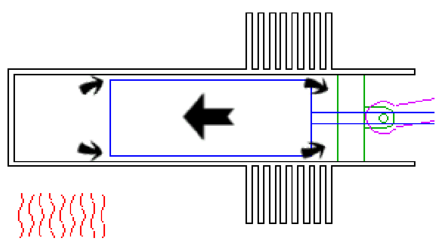

Figure 2.10: The Beta Type Transfer\

Source: Ohio.edu.stirlingengines.beta

3. **Figure 2.11** Contraction: Now the majority of the expanded gas has been shifted to the cool end. It contracts and the displacer is almost at the bottom of its cycle.

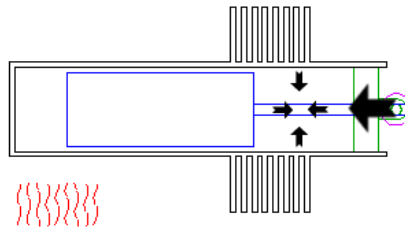

Figure 2.11: The Beta Type Contraction

Source: Ohio.edu.stirlingengines.beta

4. **Figure 2.12** Transfer: The contracted gas is still located near the cool end of the cylinder. Flywheel momentum carries the crank another quarter turn, moving the displacer and transferring the bulk of the gas back to the hot end of the cylinder. And at this point, the cycle repeats.

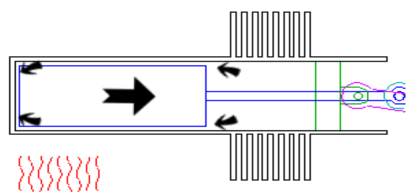

Figure 2.12: The 2nd Beta Type Transfer

Source: Ohio.edu.stirlingengines.beta

2.4.3 The Gamma Type

A gamma stirling shown in **Figure 2.13** is simply a beta stirling in which the power piston is mounted in a separate cylinder alongside the displacer piston cylinder, but is still connected to the same flywheel. The gas in the two cylinders can flow freely between them and remain a single body. This configuration produces a lower compression ratio but is mechanically simpler and often used in multi-cylinder stirling engines. Gamma type engines have a displacer and power piston, similar to beta machines, but in different cylinders. This allows a convenient complete separation between the heat exchangers associated with the displacer cylinder and the compression and expansion work space associated with the piston. Furthermore during the expansion process some of the expansion must take place in the compression space leading to a reduction of specific power.

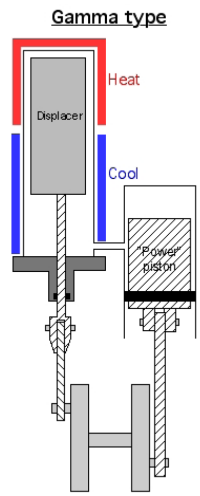

Figure 2.13: The Gamma Type

Source: Ohio.edu.stirlingengines.gamma

The advantage of this design is that it is mechanically simpler because of the convenience of two cylinders in which only the piston has to be sealed. The disadvantage is the lower compression ratio but the gamma configuration is the favorite for modelers and hobbyists.

2.5 An Overview of Flywheel

A flywheel is a rotating mechanical device that is used to store rotational energy. Flywheels have a significant moment of inertia, and thus resist changes in rotational speed. The amount of energy stored in a flywheel is proportional to the square of its rotational speed. Energy is transferred to a flywheel by applying torque to it, thereby causing its rotational speed, and hence its stored energy, to increase. Conversely, a flywheel releases stored energy by applying torque to a mechanical load, which results in decreased rotational speed.

Flywheels have three predominant uses are:

1. They provide continuous energy when the energy source is not continuous. For example, flywheels are used in reciprocating engines because the energy source (torque from the engine) is not continuously available.

2. They deliver energy at rates beyond the ability of an energy source. This is achieved by collecting energy in the flywheel over time and then releasing the energy quickly, at rates that exceed the capabilities of the energy source.

3. They control the orientation of a mechanical system. In such applications, the angular momentum of a flywheel is purposely transferred to a load when energy is transferred to or from the flywheel.

Flywheels are typically made of steel and rotate on conventional bearings. These are generally limited to a revolution rate of a few thousand RPM. Some modern flywheels are made of carbon fiber materials and employ magnetic bearings, enabling them to revolve at speeds up to 60,000 RPM. A flywheel is a spinning wheel or disc with a fixed axle so that rotation is only about one axis. Energy is stored in the rotor as kinetic energy, or more specifically, rotational energy.

2.6 Flywheel Design Considerations

There are three mainly fully coupled design factors have significant effect in the overall performance of flywheels are:

1. Material strength: basically stronger materials could undertake large operating stresses, hence could be run at high rotational speeds allowing storing more energy.

2. Rotational speed: directly control the energy stored, higher speeds desired for more energy storage, but high speeds assert excessive loads on both flywheel and bearings during the shaft design.

3. Geometry: controls the Specific Energy, in other words, kinetic energy storage capability of the flywheel. Any optimization effort of flywheel cross-section may contribute substantial improvements in kinetic energy storage capability thus reducing both overall shaft/ bearing loads and material failure occurrences.

2.7 Flywheel Design Analysis

Flywheel configuration the maximum energy density is presented, in the form of shape factor k, which is essentially dependent on the moment of inertia of the flywheel geometry. Shape factor ranges approximately between 0.3 and 1, the greater k means better performance, but in practice it is not possible to have k exactly equal to 1. Higher rpm level means the better kinetic energy level could be reached.

2.8 Finite Element Analysis Modeling

Proposed fully parametric model shown in **Figure 2.14**, where t is the thickness (t = 1.0cm) and h is the radius of the flywheel (h = 9 cm). Six flywheels geometry are constructed. Although many materials with better strength and low density are available in the market, to serve the purpose of this study, an example material properties of AISI Aluminum Alloy, with modulus of elasticity of E = 68.94 GPA, density of ρ = 2710.5 kg/m^3, poisson`s ratio of v = 0.3 is adapted in all cases. This example is taken from journal of flywheel geometric analysis.

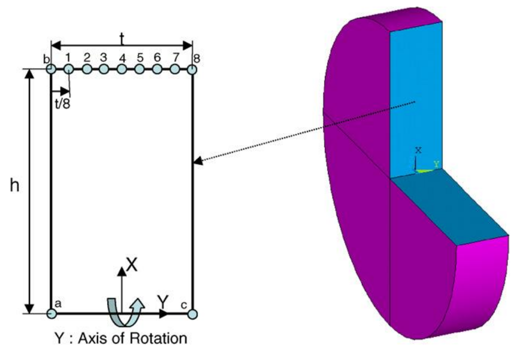

Figure 2.14: 2D view of solid flywheel model

Source: Mehmet Ali Arslan, Department of Design and Manufacturing Engineering, Gebze Institute of Technology

Six different flywheel geometries are constructed as design shown in **Figure 2.15**. All the geometry of flywheels was created and meshed using Finite Element Analysis. Displacement boundary conditions are applied at the center nodes to prevent rigid body motion in both axial and radial direction. Finally the finite element model is loaded with rotational loads and analyzed.

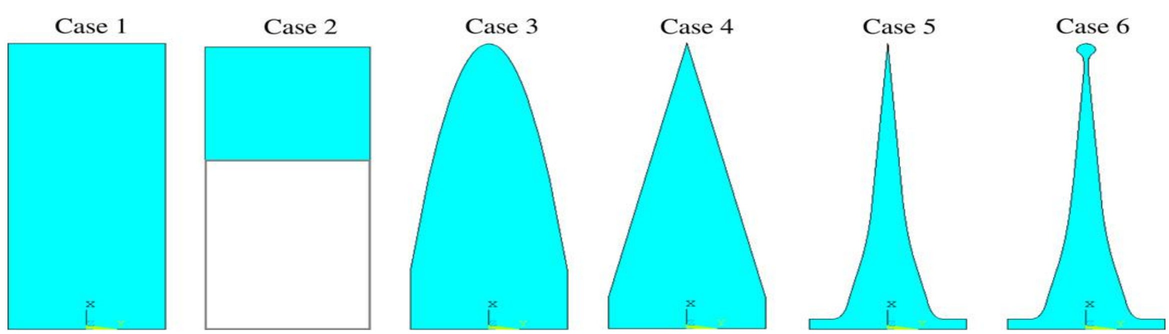

Figure 2.15: Geometry of Flywheel

Source: Mehmet Ali Arslan, Department of Design and Manufacturing Engineering, Gebze Institute of Technology

These results are shown in **Figure 2.16** and corresponding entities, kinetic energy, mass and maximum equivalent stress are also presented in **Table 2.1**. The maximum stress criterion is used as failure criterion. Minimum Equivalent stresses are calculated to be in the range of 120 -200 MPa, therefore they are considered to be within the safe stress interval. For case 1 through 4, maximum equivalent stresses occur near or close to center of the disk, but for case 5 and 6, max stress region moves toward the middle of the disk while also maintaining high stress areas close to the center.

Examining the results shows that using the annular solid disk flywheel yield the lowest Specific Energy performance no matter what the inner hole radius is chosen. Solid disk performs better than the annular disk but intuitively highest shaft load is expected since the flywheel mass in this case is the largest.

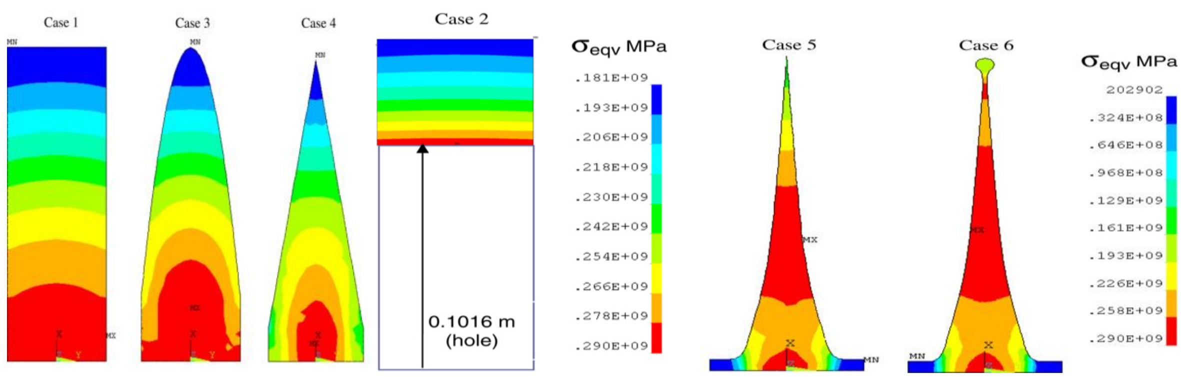

Figure 2.16: Equivalent Stress Distributions for Case 1 – Case 6

Source: Mehmet Ali Arslan, Department of Design and Manufacturing Engineering, Gebze Institute of Technology

Table 2.1: Comparison of FEA Results for All Cases

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Max. rotational speed (rpm)	19325	13140	23860	27220	31560	29900
Mass (kg)	26.798	13.8296	16.0264	10.035	3.2926	3.5202
Kinetic energy (J)	582,180	207,922	403,198	256,115	103,772	113,758
Max. $\sigma_{eqv} = \sigma_Y$ (MPa)	290	290	290	290	290	290
E_k/mass (kJ/kg)	21.7248	15.03	25.1584	25.521	31.517	32.316
E_k/mass (W-h/kg)	6.038	4.175	6.988	7.089	8.755	8.977
Best performance rank	5	6 (worst)	4	3	2	1 (best)

Source: Mehmet Ali Arslan, Department of Design and Manufacturing Engineering, Gebze Institute of Technology

2.9 Design Requirements for Stirling Engine

The following design requirements summarize the scope of the project and the final goals intended to achieve. There are design and operational elements must be assemble and function. The total engine size and weight must be safe and easy transportation if possible by 1 person. The stirling engine prototype must be mounting on a support structure for stability and safety. The engine needs to design for ease of maintenance and assembly. Next, for aesthetic and safety criteria the high temperature regions must be clearly indicated. The engine cylinder must be equipped with a removable fitting for piston inspection and pressure release. The engine prototype is estimated to cost less than RM1100. The construction materials for the support frame and engine will consist mainly of steel or aluminum, depending on cost, availability and component purpose. The precision components such as pistons, piston rings, and bearings may be purchased off the shelf or salvaged.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This methodology contain the topics such as general flow chart, literature review about the title, design geometry of flywheel, a few concept of magnetic bearing and verification the prototype and documentation about the thesis.

3.2 Flow in the Project

3.2.1 Flow Chart for PSM 1 and PSM 2

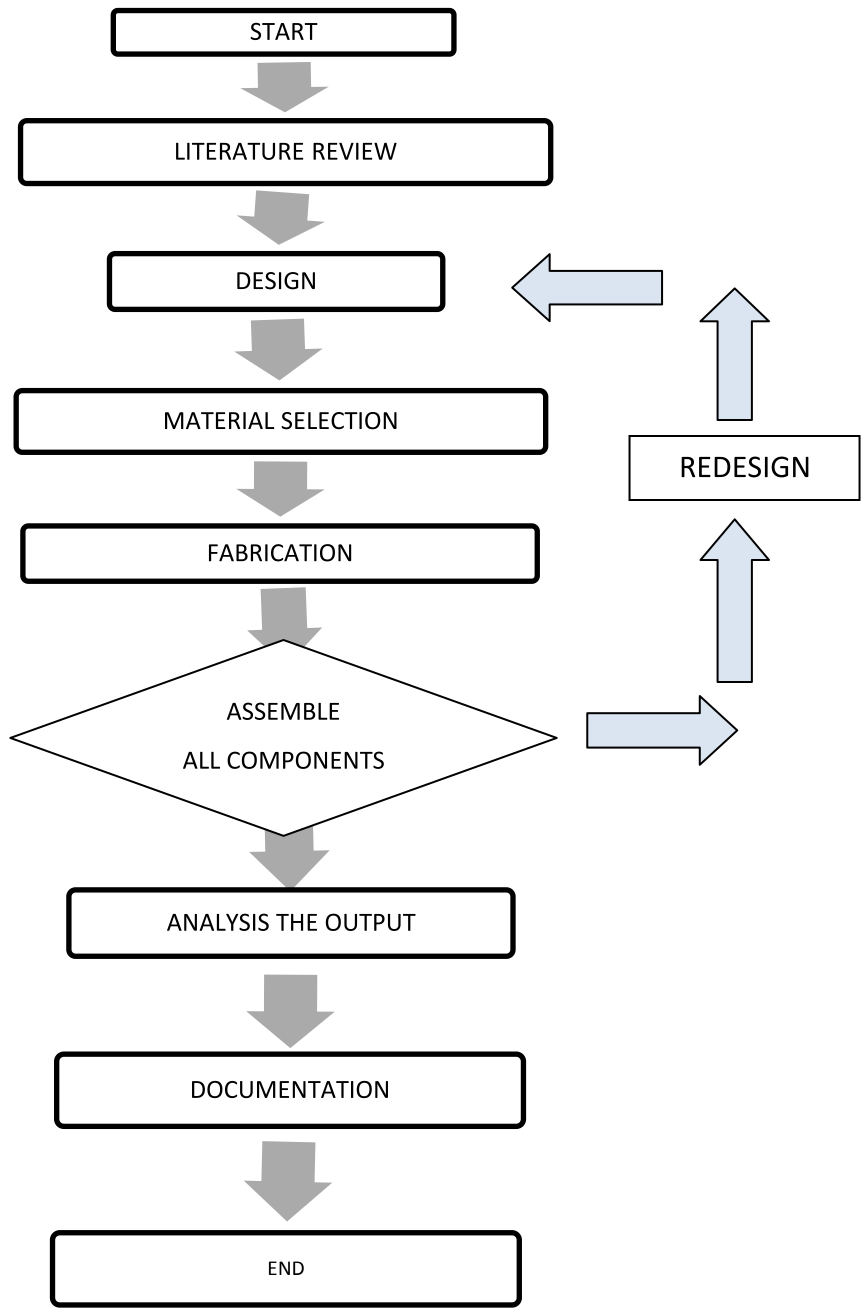

Figure 3.1: Flow Chart for PSM 1 and PSM 2

Figure 3.1 show flow chart for PSM 1 and PSM 2 of this project. This project starts with gather information. Secondly, all problem statement, concept and each components involve are identified. Thirdly, all each components was designed using SolidWorks. Then, all components will fabricate and assemble. The problem happen when some components cannot fit with each other. It is because inaccurate when machining. The component was redesign and fabricate. Then, new component was assembling with other components. The output or any data of stirling engine will be recoded. Lastly, writing the reports.

3.2.2 Gathering the Literature Review

To start this project, it is important to understand the title of the project which is Design and fabricate the small stirling engine. The scope and the objective of this project also the important thing to consider and comprehend. So, in order to get the correct and precise information to complete this project it is important to get the right source of information. The information obtain from certain source must be accurate and useful to this project. These are the certain some of the methods to get information in order to complete the literature review.

1. Browsing the internet
2. Discussion with supervisor and technical staff

i. Browsing the Internet

Internet is the one of the most important source to make the literature review and to complete this project. It became the main source due to the information regarding to this title widely spread at the internet. But not all the information from the internet is perfect information. To avoid this problem, they believe side such as internet journal from Science Direct is use to get the majority information to the literature review.

ii. Discussion with supervisor and technical staff

Getting information from discussion with the supervisor also important to make sure that the information which had gathered from the internet is correct and useful to the project. Correct information is important because valid data come from the accurate information. Furthermore with the discussion can generate new ideas and exchange of thought about the research so that the title of the research can be more clear and understandable. To produce the perfect design, the information gathered from the internet and the books will be discussed with the supervisor.

3.2.3 Design

To start the design for this prototype of a stirling engine, the report must define the suitable concept for the machine. The suitable concept for the machine can be obtained from the accurate information in literature review. The stirling engine are selected from several suitable prototype machine such as alpha type, beta type and gamma type. After selected from several concept, this stirling engine choose the suitable concept for this new invention using several factor such as simply, easy to fabricate, heavy duty and low cost. After select the suitable concept, sketch the stirling engine using the selected concept, then make the 3 Dimensional Model for the sketched model using Solid works software.

3.2.4 Decicion

From all 3 types of stirling engine which are alpa, beta and gamma types, the gamma type which can adapt for the required movement for stirling engine are choosen. This type was choose because only this concept fulfill the criteria selection for this project which is simple, low cost, heavy duty and easy to manufacture. Adaptation from this concept with alpha type with two pistons, placed likes piston in gamma type also make the new invention for this project.

3.2.5 3D Modeling

After complete sketch for this new invention, the next stage is transferred the sketching in 3 Dimension Model using SolidWorkd software. Appendix B showed engineering drawing for this prototype of a stirling engine.

3.2.6 Material Selection

There are many components in this stirling engine which are flywheel, flywheel support, stirling base, hot and cold cylinder piston, connector cylinder, hot and cold base, pin hold, cranks, hot and cold piston, piston rod and bracket. Five different types of materials that use in this stirling engine are aluminum, mild steel, brass, prospect and graphite. Aluminum materials are uses for flywheel, flywheel support, stirling base, hot and cold cylinder piston, hot and cold base and pin hold. Graphite materials are uses for hot and cold piston. Mild steel material is uses for bracket. Prospect material is uses for connector cylinder hot and cold. Brass materials are uses for cranks.

Aluminum was choose because it is light in weight, easy to fabricate and widely available. The graphite was choose because it is heat resistance, good hardness, better toughness, longer melting time, higher purity and less impurities. Physical properties for mild steel are Mild steel is very strong due to the low amount of carbon. Mild steel has a high resistance to breakage. Mild steel, as opposed to higher carbon steels, is quite malleable, even when cold. This means it has high tensile and impact strength. Higher carbon steels usually crack under stress, while mild steel bends or deforms. Brass are high tensile strength, lower elongation in fact elongation increases with the amount of Zinc. Good in hardness and high density compared other substances.

3.2.7 Fabrication

In this process, suitable machining processes for all components were firstly defined. Then every machining process to be used in making all components must be learning before making any machining. This is to ensure safety and gather knowledge about every machine function and limitation. The training of the machine will be supervised by the workshop technician for safety and operation. After that, every component will be machine according to suitable machining process required. This process will be guided by the engineering drawing. After all parts and component were ready, assembly process was next. Before that, the finishing process of the components was done. This is to ensure the dimension was matched with the engineering drawing. All the assemblies were base on engineering drawing. The assembly started with the simple and small system before goes to bigger system. Then all system was assembled carefully.

3.3 Significant in the Methodology

3.3.1 Design

In this chapter, the important part is in design because this prototype must be compliance to several aspects. The design consideration must be done carefully so the design can be fabricated and the system functioning. The aspects that must be considered in designing the machine are:

1. Strength: The toughness of the piston, piston rod, cylinder hot and cold also the connector to the flywheel will be the most important criteria in designing the machine.

2. Material: Material availability will be one of the challenges in the design consideration. The most important in material selection is easy to find and suitable to use.

3. Cost: The cost of the whole machine must no exceeded budget given and must be reasonable. The design cost must also efficient and reduce waste and losses.

4. Functionality: This prototype function is an important aspect to make sure the piston and flywheel move.

5. Weight: Weight is one more important aspect to consider in designing this prototype so this prototype can be easily to store and light weight.

3.3.2 Cylinder Component Design

To maximize the heat transfer between the cold cylinder and the surrounding water bath a simple array of annular fins was designed to increase the external surface area of the cylinder. Chapter 4 will explain the heat transfer calculation for aluminum; show an approximate 320 – 400% increase in heat transfer with the addition of a fin 9mm in length. Based on these calculations aluminum was selected as the cold cylinder material as it enable a larger heat transfer when compared to brass. Other benefits of choosing aluminum over brass are that it will not rust in the ice bath and it has improved dry frictional characteristics with brass.

A large number of fins with spacing 2.5 times chose the thickness to ensure maximum surface area. Because the system involves free convection it was important to choose large fin spacing. By increasing the water volume between the fins the result is effectively an increase in the engine efficiency. A larger volume of water between fins will take longer to heat up, thus maintaining a higher temperature differential for an extended period of time.

3.3.3 Material Selection

i. Bill of Material

Table 3.1: Bill of Material

No	Part	Material	Dimension (mm)	Remark
1	Flywheel	Aluminum	ϕ 100 x 8	Fabricate
2	Flywheel Support	Aluminum	110 x 30 x 25	Fabricate
3	Stirling Base	Aluminum	180 x 77 x 8	Fabricate
4	Hot Cylinder Piston	Aluminum	ϕ 32 x 160	Fabricate
5	Cold Cylinder Piston	Aluminum	ϕ 32 x 140	Fabricate
6	Connector – Cylinder hot	Prospect	ϕ 15 x 63	Fabricate
7	Connector – Cylinder cold	Prospect	ϕ 15 x 38	Fabricate
8	Hot & Cold Base	Aluminum	110 x 75 x 10	Fabricate
9	Bracket	Mild steel	25 x 20	Fabricate
10	Pin hold	Aluminum	ϕ 15 x 23	Fabricate
11	Cranks	Brass	ϕ 30 x 7	Fabricate
12	Bearing	-	ϕ 10	Standard part
13	Hot Piston	Graphite	ϕ 29	Standard part
14	Cold Piston	Graphite	ϕ 18	Standard part
15	Hot Piston Rod	Brass	ϕ 2.6	Standard part
16	Cold Piston Rod	Brass	ϕ 2.6	Standard part
17	Bolt & nut	-		Standard part

ii. Material Properties and Mechanical Properties

a) Aluminum

Material properties for aluminum are stable in air and resistant to corrosion by seawater and many aqueous solutions and other chemical agents. This is due to protection of the metal by a tough, impervious film of oxide. At purity greater than 99.95%, aluminum resists attack by most acids but dissolves in aqua regain. Its oxide film dissolves in alkaline solution, and corrosion is rapid. Aluminum is amphoteric and can react with mineral acids to form soluble salts and to evolve hydrogen.

There are mechanical properties for aluminum are density: 2600-2800 kg/m^3, melting point: 660 °C, elastic modulus: 70-79 GPa, poisson's ratio: 0.33, tensile strength: 230-570 MPa, yield strength: 215-505 MPa, percent elongation: 10-25%, thermal expansion coefficient: 20.4-25.0 × 10^{-6}/K and thermal conductivity: 237 W/m-K

b) Graphite

Material properties for graphite are high specific stiffness (stiffness divided by density), high specific strength (strength divided by density), and extremely low coefficient of thermal expansion (CTE). Graphite also good electrical conductive and insoluble in water as well as other organic solvents. Graphite has a high melting point above 3000º, like that of diamond, the other allotrope of carbon. Hence, it is stable over a wide range of temperatures. Graphite is very soft and has a greasy texture. It can be broken easily and leaves a black streak on the hand when touched. Although graphite is soft and flexible, it is not elastic in nature.

c) Brass

Material properties for brass is strength, machinability, ductility, wear-resistance, hardness, colour, antimicrobial, electrical and thermal conductivity, and corrosion-resistance. Brass is available in a very wide variety of product forms and sizes to allow minimum machining to finished dimensions. Brass does not become brittle at low temperatures like mild steel. Brass also has excellent thermal conductivity making it a first choice for heat exchangers (radiators). Its electrical conductivity ranges from 23 to 44% that of pure copper.

Mechanical properties for graphite are density: 8.49 g/cc, melting point: 885 - 900 °C, modulus of elasticity: 97 GPa, poisson's ratio: 0.31, tensile strength ultimate: 338 - 469 MPa, tensile strength yield: 124 - 310 MPa and thermal conductivity: 115 W/m-K.

d) Mild Steel

Mild steel is a type of steel alloy that contains a high amount of carbon as a major constituent. The mild steel composition are 2 % carbon in the manufacture of carbon steel, the proportions of manganese (1.65%), copper (0.6%) and silicon (0.6%) are fixed, while the proportions of cobalt, chromium, niobium, molybdenum, titanium, nickel, tungsten, vanadium and zirconium are not. A high amount of carbon makes mild steel different from other types of steel. Carbon makes mild steel stronger and stiffer than other type of steel. However, the hardness comes at the price of a decrease in the ductility of this alloy. Carbon atoms get affixed in the interstitial sites of the iron lattice and make it stronger. Mildest grade of carbon steel or 'mild steel' is typically carbon steel, with a comparatively mild amount of carbon (0.16% to 0.19%).

The mechanical properties of mild steel are density is 7.85 gm/cm3. Its Young's modulus, which is a measure of its stiffness, is 210,000 Mpa, poisson's ratio: 0.29, tensile strength ultimate: 540 MPa, tensile strength yield: 415 MPa and thermal conductivity: 51.9 W/m-K.

3.3.4 Fabrication Part

a) Part 1: Fabrication of Flywheel.

Table 3.2: Steps to fabricate flywheel

Step	Operation Description	Tools
Step 1	Cut raw material $\phi 100$	Conventional Bench Saw
Step 2	Rim hole design	CNC Milling
Step 3	Facing until 8 mm thickness.	CNC Milling

Table 3.2 above shows the steps to fabricate flywheel. Firstly, the raw material with dimension $\phi 100$ mm was selected. Secondly, master cam software was used to design follow required dimension. The coding used in master cam was applied to CNC milling. Then, make a rim hole and hole for screw dimension 4mm. Finishing was applied to get the size ϕ 100 mm x 7 mm. Chamfer the sharp edge and clean the flywheel as shown in Figure 3.2.

Figure 3.2: Flywheel

b) Part 2: Fabrication of Flywheel Support

Table 3.3: Steps to fabricate flywheel Support

Step	Operation Description	Tools
Step 1	Cut raw material into 110 x 25 x 20	Conventional Bench Saw
Step 2	Facing the surface	Milling Machine
Step 3	Drill ϕ 10	End mill ϕ 10
Step 4	Grooving	End mill ϕ 18
Step 5	Cut top head	Linear precision saw machine
Step 6	Drill ϕ 3	Drill bit ϕ 3
Step 7	Bearing with inside diameter ϕ 3	Force fit

Table 3.3 above shows the steps to fabricate flywheel support. Firstly, the raw material from store will cut into dimension 110 mm x 30 mm x 25 mm. The entire surface was facing. The drill bit ϕ 10 mm was secured properly into milling machine. Drill holes at specific mark. Grooving was making in the middle of part. The top of the head was cut into two with linear precision saw machine. The drill bit ϕ 3 mm was secured properly into milling machine. Drill holes at specific mark. Force fit the bearing with internal diameter ϕ 3 mm into the diameter ϕ 10 mm hole. Lastly chamfer was made at entire side of component as shown in figure 3.3.

Figure 3.3: Flywheel support

c) Part 3: Fabrication of Stirling Base

Table 3.4: Steps to fabricate Stirling Base

Step	Operation Description	Tools
Step 1	Cut raw material into 180 x 77 x 8	Conventional Bench Saw
Step 2	Punch centre hole	Puncher
Step 3	Drill $\phi 4$	Drill bit $\phi 4$
Step 4	Drill $\phi 8$	End mill $\phi 8$

Table 3.4 above shows the steps to fabricate stirling base. Firstly, the raw material from store will cut into dimension 180 mm x 77 mm x 8 mm. Secondly; the centre of drill was made by punch with puncher. The drill bit $\phi 4$ mm was secured properly into drilling machine. Drill three holes at specific mark. The end mill $\phi 8$ mm was secured properly into milling machine to make a counter bore. Drill three holes at specific mark. Lastly, chamfer the sharp edge as shown in figure 3.4 below.

Figure 3.4: Stirling base

d) Part 4: Fabrication of Connector – cylinder cold

Table 3.5: Steps to Fabricate Connector – Cylinder cold

Step	Operation Description	Tools
Step 1	Cut raw material into 15 x 53	Horizontal Bench Saw
Step 2	Drill $\phi 10$	End mill $\phi 10$
Step 3	Bearing with inside diameter $\phi 3$	Force fit

Table 3.5 above shows the steps to fabricate connector cylinder cold. Firstly, the raw material was cut into dimension 15 mm x 53 mm. The end mill $\phi 10$ mm was secured properly into milling machine. Drill the marking hole. Force fit the bearing with internal diameter $\phi 3$ mm into the diameter $\phi 10$ mm hole. Chamfer was made to get the round shape around the bearing. The surface and the edges of connector was facing until the length and width are 15 mm x 52.50 mm as shown in figure 3.5 below.

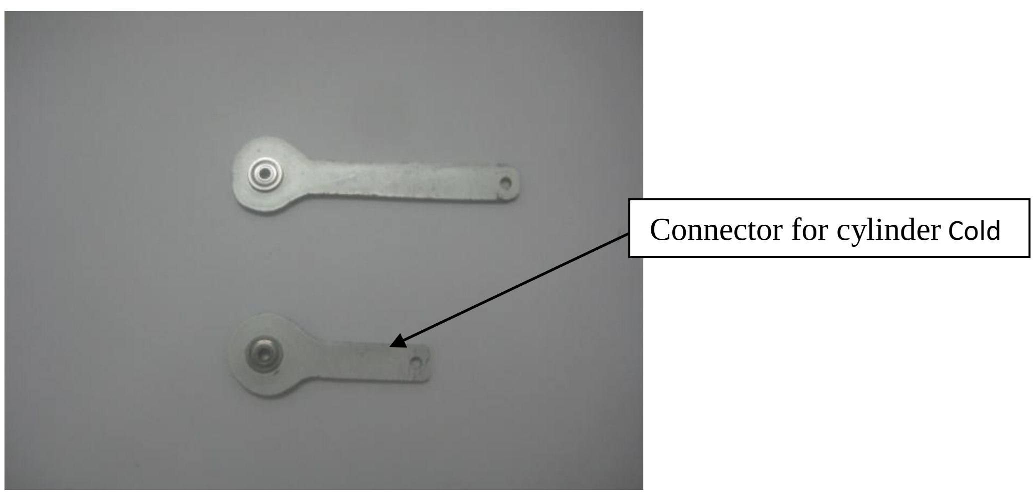

Figure 3.5: Connector – cylinder cold

e) Part 4: Fabrication of Connector – cylinder hot

Table 3.6: Steps to Fabricate Connector – Cylinder hot

Step	Operation Description	Tools
Step 1	Cut raw material into 15 x 78	Horizontal bench Saw
Step 2	Drill $\phi 10$	End mill $\phi 10$
Step 3	Bearing with inside diameter $\phi 3$	Force fit

Table 3.6 above shows the steps to fabricate connector cylinder hot. Firstly, the raw material was cut into dimension 15 mm x 78 mm. The end mill $\phi 10$ mm was secured properly into milling machine. Drill the marking hole. Force fit the bearing with internal diameter $\phi 3$ mm into the diameter $\phi 10$ mm hole. Chamfer was made to get the round shape around the bearing. The surface and the edges of connector was facing until the length and width are 15 mm x 77.5 mm as shown in figure 3.6 below.

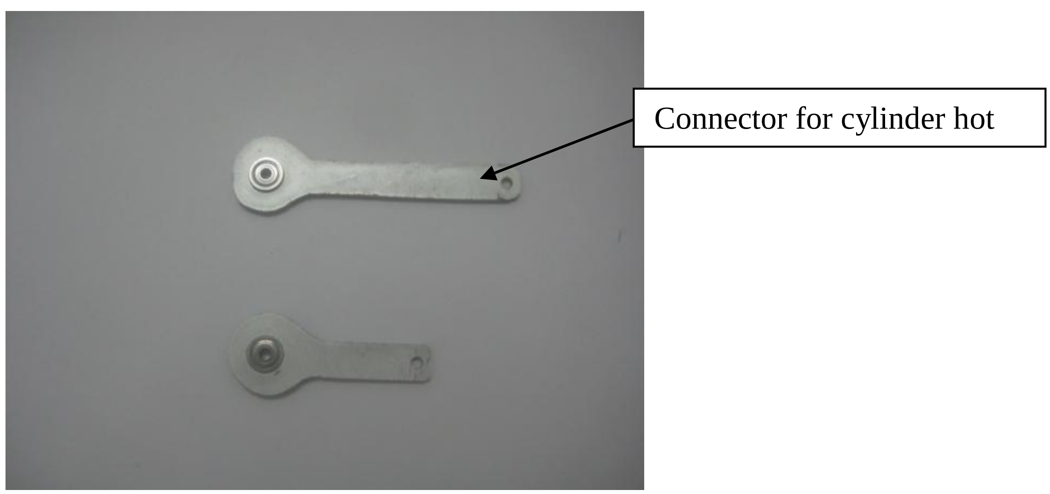

Figure 3.6: Connector – cylinder hot

f) Part 6: Fabrication of Bracket

Table 3.7: Steps to Fabricate Bracket

Step	Operation Description	Tools
Step 1	Cut material into 76 x 25 x 20	Cutter
Step 2	Punch centre hole	Puncher
Step 3	Drill $\phi 4$	Drilling machine

Table 3.7 above shows the steps to fabricate bracket. Firstly, the raw material from store was cut into dimension 76 mm x 25 mm x 20 mm. Puncher was used to make centre of drill. The drill bit $\phi 4$ mm was secured properly into drilling machine. Drill two holes at specific mark. Chamfer was made at the up and down side of component as shown in figure 3.7 below.

Figure 3.7: Bracket

g) Part 7: Fabrication Cold Cylinder Piston

Table 3.8: Steps to Fabricate Cold Cylinder Piston

Steps	Operation Description	Tools
Step 1	Cut raw material ϕ50 x 140	Conventional Bench saw
Step 2	Lathe until dimension ϕ32	Lathe machine
Step 3	Grooving process	Parting tool
Step 4	Drill centre drill	Centre drill
Step 5	Drill ϕ10	Drill bit ϕ10
Step 6	Boring 20	Boring tool
Step 7	Cut into 60 mm length	Horizontal bench saw
Step 8	Drill 2.6	Drill bit 2.6w
Step 9	Thread	M3

Table 3.8 above shows the steps to fabricate cold cylinder piston. Firstly, raw material with dimension ϕ50 mm was selected. The raw material was cut into 140 mm using conventional saw. Then, the work piece was placed properly into lathe machine and make turning process until diameter of the work piece become ϕ32 mm. Parting tool was placed properly into lathe machine and grooving process was started. Centre drill was used in Lathe machine to make the centre drill at front surface. Drill bit sizes ϕ10 mm was used and drill the work piece until the drill through at other side. Boring tool was put inside the Lathe machine and boring process was started until the dimension is ϕ20 mm. The diameter outside of cylinder was finishing about 2 mm. Horizontal bench saw was used to cut the work piece into 60 mm length. Drill bit sizes ϕ2.6 mm were placed properly into milling machine to make four holes in front of the surface. Then, thread M3 was used and makes a thread at four holes. Chamfer the sharp edge and clean the cold cylinder piston as shown in figure 3.8 below.

Figure 3.8: Cold Cylinder Piston

h) Part 8: Fabrication Hot Cylinder Piston

Table 3.9: Steps to Fabricate Hot Cylinder Piston

Steps	Operation Description	Tools
Step 1	Cut raw material ϕ50 x 160	Horizontal bench saw
Step 2	Lathe until dimension ϕ32	Lathe machine
Step 3	Grooving process	Parting tool
Step 4	Drill centre drill	Centre drill
Step 5	Drill ϕ10	Drill bit ϕ10
Step 6	Boring ϕ20	Boring tool
Step 7	Cut into 82 mm length	Horizontal bench saw
Step 8	Drill 2.6	Drill bit 2.6
Step 9	Thread	M3

Table 3.9 above shows the steps to fabricate hot cylinder piston. Firstly, raw material with dimension ϕ50 mm was selected. Raw material was cut into 160 mm using conventional saw. The raw material was placed properly into lathe machine and make turning process until diameter in front of the work piece become ϕ32 mm. Parting tool was

placed properly into lathe machine and grooving process was started. Only half of the work piece length does the grooving process. Turning process was doing in other half part of work piece until diameter ϕ23 mm. Centre drill was used in lathe machine to make the centre drill at front surface. Drill bit sizes ϕ10 mm was used and drill the work piece until 80mm length. Boring tool was put inside the lathe machine and boring process was started until the dimension is ϕ20 mm. The outside diameter cylinder was finishing about 2mm. Next, horizontal bench saw was used to cut the work piece into 82 mm length. Drill bit sizes ϕ2.6 mm were placed properly into milling machine to make four holes in front of the surface. Thread M3 was used and makes a thread at four holes. Lastly, chamfer the sharp edge and clean the cold cylinder piston as shown in figure 3.9.

Figure 3.9: Hot Cylinder Piston

i) Part 9: Fabrication Cranks

Table 3.10: Steps to Fabricate Cranks

Steps	Operation Description	Tools
Step 1	Cut raw material $\phi 30$	CNC Milling
Step 2	Drill $\phi 4$	CNC Milling
Step 3	Drill $\phi 2.7$	CNC Milling
Step 4	Thread	M3

Table 3.10 above shows the steps to fabricate the cranks. Firstly, raw material with dimension $\phi 30$ mm was selected. Master cam software was used to design the dimension. The coding used in master cam was applied to CNC milling to make hole and hole for screw dimension 3 mm. Next, thread with M3 was applied into the hole of screw. Lastly, chamfer the sharp edge and clean the crank as shown in figure 3.10.

Figure 3.10: Cranks

j) Part 10: Fabrication of Hot & Cold Base

Table 3.11: Steps to Fabricate Hot & Cold Base

Steps	Operation Description	Tools
Step 1	Cut raw material 120 x 75 x 10	Conventional Saw
Step 2	Mark and punch eleven centre of hole	Puncher
Step 3	Drill $\phi 4$	Drill bit $\phi 4$
Step 4	Drill $\phi 4.5$	Drill bit $\phi 4.5$
Step 4	Drill $\phi 8$	Drill bit $\phi 8$
Step 5	Drill $\phi 8.5$	End mill $\phi 8.5$

Table 3.11 above shows the steps to fabricate hot and cold base. Firstly, raw material with dimension 120 mm x 75 mm x 10 mm was cut using conventional saw. Secondly, roughing and finishing process about 10 mm length. Puncher was used to make entire centre of drill. The drill bit $\phi 4$ mm was secured properly into milling machine. Drill three holes at the bottom and the side of stirling base. The drill bit $\phi 4.5$ mm was secured properly into milling machine. Drill eight holes at specific mark. The end mill $\phi 8.5$ mm was secured properly into milling machine and three holes were drilled to make counter bore. Lastly, the hot and cold base was finishing about 3 millimeter thickness using milling machine as shown in figure 3.11.

Figure 3.11: Hot and Cold Base

K) Part 11: Fabrication on Pin Hold

Table 3.12: Steps to Fabricate Pin Hold

Steps	Operation Description	Tools
Step 1	Cut raw material ϕ15 x 23	CNC Milling
Step 2	Drill ϕ5	CNC Milling

Table 3.12 above shows the steps to fabricate pin hold. Firstly, raw material was cut with dimension ϕ15 mm x 23 mm. Master cam software was used to design the dimension. The coding used in master cam was applied to CNC milling to make a hole with diameter 5 millimeter. Lastly, chamfer the sharp edge and clean the crank as shown in figure 3.12.

Figure 3.12: Pin Hold

L) Standard Part

Table 3.13: Standard Part

No	Part	Remark
1	Bearing	Standard Part
2	Bolt and nut	Standard Part
3	Piston	Standard Part
4	Piston rod	Standard Part

a) Standard Part 1 is a bearing with inner size $\phi 3$ mm with SKF brand.

b) Standard Part 2 is bolt and nut. The diameter of bolt is $\phi 4$. The diameter of nut is $\phi 8.5$ mm.

c) Standard Part 3 is a piston. The piston material is from graphite with diameter $\phi 20$ mm.

d) Standard Part 4 are piston rod. The piston rod material is from brass with diameter $\phi 2.6$ mm.

Figure 3.13: Piston

Figure 3.14: Bearing

Figure 3.15: Piston Rod

Figure 3.16: Bolt & Nut

3.3.5 Assembly

1. First subassembly

The first subassembly consists of flywheel, flywheel support, 2 units bearing, 2 unit connector hot and cold, also 2 unit pin hold. Take all this parts. Assemble the flywheel with pin hold and tie with Allen bolt. Assemble the flywheel support to pin hold. Then, assemble crank and connector. All part ties with Allen bolt. Make sure the fasteners secured properly. Use Allen key to tie the entire Allen bolt.

2. Second subassembly

The second subassembly consists of cold and hot base, cylinder hot, cylinder cold, piston and piston rod. The piston was tie together with piston rod. That piston will put in the cold and hot cylinder. The cold and hot cylinder was fastened with cold and hot base. The piston rod was jointed with connector at the flywheel.

3. Base subassembly

The base subassembly consists of assemble of the flywheel and assemble of the cold and hot base. The two subassemblies were fastened together on the main base. All the first and second subassembly was fastened properly with bolt and nut.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will focus on results and discussion. Further discussion can be divided into two, which is completely fabricating the stirling engine using several criteria, and performance of this machine will be analyzed.

Figure 4.1 shown the complete stirling engine and this machine analysis with several aspect. Analysis is the study of such constituent parts and their interrelationships in making up this machine. Analysis is one of the important parts because from analysis, the function and the strength of this machine can be analyzed and confirmed. The verification of function for this machine can be seen with the naked eyes but the analysis such as air compression, temperature change, volume of working space and the pressure of this machine must be done with experimental and some theoretical calculations.

Figure 4.1: Complete Assemble of Stirling Engine

4.2 Fin Heat Transfer

To prove the effectiveness of adding external fins to the cold cylinder a heat transfer analysis was carried out. Calculations were carried out for both aluminum and brass. The results are shown in table 4.5. Figure 4.2 show the diagram of cold cylinder as an example of heat transfer analysis.

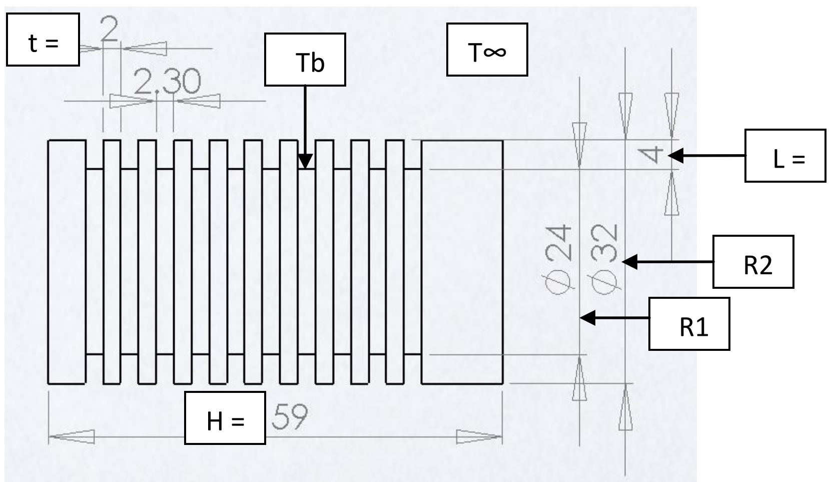

Figure 4.2: Diagram of Cold Cylinder

Table 4.1: Cool Water Bath Criteria

Water bath		Units
T∞	273	˚K
h	60	W / m^2 K

Source: Stirling Engine Society, SESUSA. (2006).

Table 4.2: Cylinder Dimension

Dimensions		**Units**
Height, H	0.059	m
Radius r_1	0.012	m
Radius r_2	0.016	m
Length, L	0.004	m
Thickness, t	0.002	m

Table 4.3: Material Aluminum Cylinder

Material	**Aluminum**	
		Units
T_b	278	˚K
θ_b	5	˚K
N	9	
K	237	W / $m\ K$

N=No. of Fins

$T_{b=}Base\ temperature$

K= Thermal Conductivity

$\theta_b = T_b - T_\infty$

= (278 – 273) ˚K

= 5 ˚K

$r_{2c} = r_2 + \frac{t}{2}$

= 0.016 + $\frac{0.002}{2}$

= 0.017 m

$A_f = 2\pi(r2c^2 + r1^2)$

= $2\pi(0.017^2 + 0.012^2)$

= 0.0027206 m^2

$A_t = NA_f + 2\pi r_1 (H - Nt)$

$= (9 \times 0.0027206) + 2\pi \times 0.012(0.059 - 9 \times 0.002)$

$= 0.02758\ m^2$

$\frac{r_{2c}}{r_1} = \frac{0.017}{0.012} = 1.4167\ m$

$$L_c = L + \frac{t}{2} = 0.004 + \frac{0.002}{2} = 0.005\ m$$

$$A_p = L_c\, t = 0.005 \times 0.002 = 0.00001\ m^2$$

$$L_c^{\frac{3}{2}} (\frac{h}{kA_p})^{1/2} = 0.005^{\frac{3}{2}}(\frac{60}{237 \times 1 \times 10^{-5}})^{1/2} = 0.05625$$

From graph $\eta_f = 0.97$

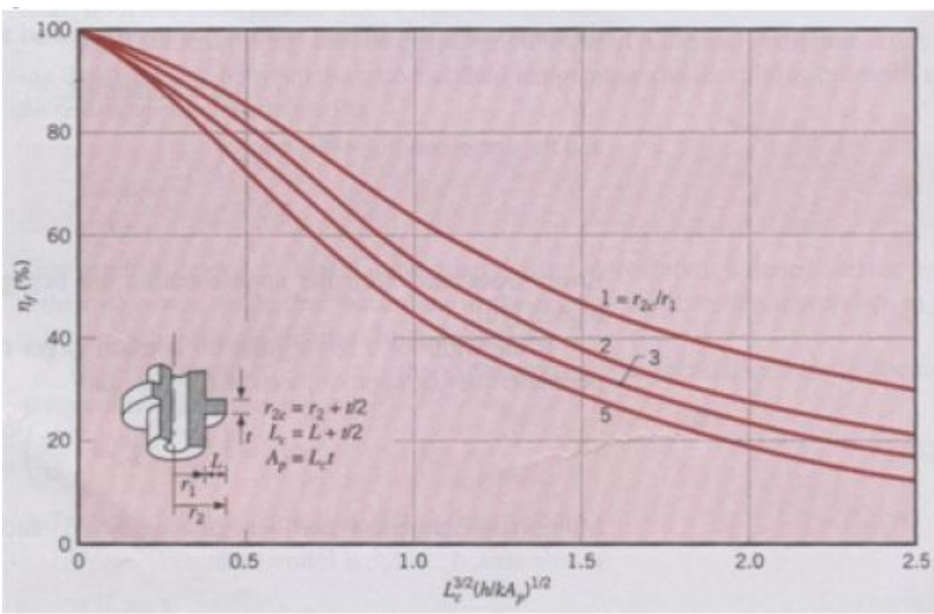

Figure 4.2: Graf of Heat Transfer Efficiency

Source: Incropera, Frank P., Introduction to Heat Transfer, 2007

Table 4.4: Calculation Summary

A_f	0.0027206	m^2
A_t	0.02758	m^2
$\frac{r_{2c}}{r_1}$	1.4167	m
L_c	0.005	m
r_{2c}	0.017	m
A_p	0.00001	m^2

Heat transfer with fins:

$$q_t = hA_t[\left(1 - \frac{NA_f}{A_t}\left(1 - \eta_f\right)\right]\theta_b = \ 60 \times 0.02758[1 - \frac{9 \times 0.0027206}{0.02758}(1 - 0.97)] \times 5$$

= 8.0536 W

Heat transfer without fins:

$$q_{wo} = h(2\pi r_1 H)\theta_b = \ 60(2\,\pi \ \times 0.012 \times 0.059)5 = 1.3345\ w$$

Percent Increase = $\frac{q_{wo} - q_t}{q_{wo}} \times 100 = \frac{1.3345 - 8.0536}{1.3345} \times 100 = 503\ \%$

Table 4.5: Summary Result

Material	**Aluminum**	**Brass**
With fin	8.0536 w	7.88326 w
Without fin	1.3345 w	1.3345 w
η_f	0.97	0.94

As a result of this analysis as show in table 4.5, the initial fin length of 4mm for aluminum show a higher value in heat transfer. The fin length, in theory, should have been increased to 20mm for maximum heat transfer in aluminum. When using aluminum for the cylinder material the heat transfer continues to increase with fin length; this is due to its high thermal conductivity. However; due to frame clearance issues, material available and ease of machining a fin length of 4mm with material aluminum was chosen. With this fin length there is an approximate 486% increase in heat transfer for brass and 503% for aluminum. The efficiency by using aluminum also gives the approximate near 1. From the journal brass were more suitable uses for cold cylinder material as it enabled a larger heat transfer when compared to aluminum or steel. Other benefits of using brass that it will not rust in the ice bath and it has improved dry frictional characteristics means brass is a self lubricating metal with aluminum or steel.

4.3 Schmidt Analysis of Ideal Isothermal Model

To determine the theoretical energy output an ideal isothermal analysis was performed on a simplified model of the final engine design. The ideal isothermal analysis is incapable of predicting results for the real cycle but can be used as a guide for design refinement purposes and to gauge the maximum theoretical capabilities of the engine. The assumptions of an ideal isothermal model are defined below:

1. Temperature of compression space/cold cylinder is at the lower limit of the cold sink
2. Temperature of expansion space/hot cylinder is at the upper limit of the hot sink
3. Heat exchangers are 100% effective
4. Regenerator is 100% effective
5. Volume of the working spaces vary sinusoidally with crank angle

Table 4.6: Value of Design

Design	Value
Dcyl (m)	0.01585
Lcyl (m)	0.0295
Dtube (m)	0.00295
Ltube (m)	0.036
T_H (K)	573
T_L (K)	273
T_r (K)	404.6323
V_c (m^3)	5.8206×10^{-6}
V_k (m^3)	0
V_r (m^3)	2.4606×10^{-7}
V_h (m^3)	0
V_e (m^3)	5.8206×10^{-6}
$V_{cl,c}$ (m^3)	0
$V_{cl,e}$ (m^3)	0
$V_{sw,e}$ (m^3)	5.8206×10^{-6}
$V_{sw,c}$ (m^3)	5.8206×10^{-6}
R(J/(kg*K))	287.05
Vmax (m^3)	0.000017384 (estimate)
n (RPM)	300(estimate)

- $V_{cl} = clearance\ volume$
- $V_{sw} = swept\ (stroke) volume$
- $\theta = crank\ angle$
- $\alpha = phase\ angle\ \left(\alpha = \frac{\pi}{2}\right)$
- $Compression\ space, c$
- $Cooler, k$
- $Regenerator, r$
- $Heater, h$
- $Expansion\ space, e$

$PV = mRT(Ideal\ Gas\ Law)$

(101325)(0.000017384) = m (287.05) (293)

m = 0.0000209431 kg

$$\alpha\ (phase\ angle) = \frac{\pi}{2} = 1.5708\ rad$$

$$s = \left[\left(\frac{v_{sw,c}}{2T_L} + \frac{v_{cl,c}}{T_L}\right) + \frac{v_k}{T_L} + \frac{v_r \ln(T_H/T_L)}{T_H - T_L} + \frac{v_h}{T_H} + \left(\frac{v_{sw,e}}{2T_H} + \frac{v_{cl,e}}{T_H}\right)\right]$$

$$= [(\frac{5.8206\ \times 10^{-6}}{2 \times 273} + 0 + \frac{2.4606\ \times 10^{-7} ln\, 573/273}{573 - 273} + 0 + \left(\frac{5.8206\ \times 10^{-6}}{2 \times 573} + 0\right)]$$

$$= 1.0660x10^{-8} + 6.08108x10^{-10} + 5.0791x10^{-9} = 1.63476x10^{-8}\ m^3/K$$

$$c = \frac{1}{2}\sqrt{(\frac{v_{sw,e}}{T_H})^2 + 2\left(\frac{v_{sw,e}v_{sw,c}}{T_H T_L}\right)\cos\alpha + (\frac{v_{sw,c}}{T_L}^2)}$$

$$= \frac{1}{2}\sqrt{(\frac{5.8206\ \times 10^{-6}}{573})^2 + 2\left(\frac{5.8206\ \times 10^{-6} x 5.8206\ \times 10^{-6}}{573\ x\ 273}\right)\cos 1.5708 + (\frac{5.8206\ \times 10^{-6}}{273})2}$$

$$= 1.57382x10^{-8}\ m^3/K$$

$$(ratio) b = \frac{c}{s} = \frac{1.57382x10^{-8}}{1.63476x10^{-8}} = 0.96272$$

$$\beta = tan^{-1}(\frac{v_{sw,e(sin\alpha)/T_H}}{v_{sw,e(cos\alpha)/T_H + v_{sw,c}/T_L}})$$

$$= tan^{-1}(\frac{5.8206\ \times 10^{-6}(\sin 1.5708)/573}{5.8206\ \times 10^{-6}(cos 1.5708)/573 + 5.8206\ \times 10^{-6}/273})$$

$$= 0.50687\ rad$$

Table 4.7: Value of Parameter

Parameter	Value
$T_{ambient}\ (K)$	293
$P_{charged}\ (Pa)$	101325
M (Kg)	0.0000209431
$\alpha\ (rad)$	1.5708
$s\ (m^3/k)$	$1.63476x10^{-8}$
$c\ (m^3/k)$	$1.57382x10^{-8}$
b	0.96272
$\beta\ (rad)$	0.50687

$$P_{mean} = \frac{MR}{\sqrt[s]{1-b^2}} = \frac{0.0000209431 \times 287.05}{1.63476x10^{-8}\sqrt{1-0.96272^2}} = 1.3595\ MPa$$

$$P_{min} = \frac{MR}{s(1+b)} = \frac{0.0000209431 \times 287.05}{1.63476x10^{-8}(1+0.96272)} = 187.3640\ kPa$$

$$P_{max} = \frac{MR}{s(1-b)} = \frac{0.0000209431 \times 287.05}{1.63476x10^{-8}(1-0.96272)} = 9.86435\ MPa$$

$$W_c = \frac{1}{b}\pi V_{sw,c}P_{mean}\sin\beta\left(\sqrt{1-b^2}-1\right)$$

$$= \frac{1}{0.96272}\ \pi \times 5.8206\ \times 10^{-6} \times 1.3595\ MPa \times \sin 29(\sqrt{1-0.96272^2}-1)$$

= - 9.13246 J

$$W_e = \frac{1}{b}\pi V_{sw,e}P_{mean}\sin(\beta-\alpha)\left(\sqrt{1-b^2}-1\right)$$

$$= \frac{1}{0.96272}\pi \times 5.8206\ \times 10^{-6} \times 1.3595\ MPa \times \sin(29-90)(\sqrt{1-0.96272^2}-1)$$

$$= 16.4752\ J$$

$$(Cycle\ Work\ Integral)\ W_{net} = W_e + W_c = 16.4752 + (-9.13246\ ) = 7.34274\ J$$

$$power = \frac{RPM}{60} \times W_{net} = \frac{300}{60} \times 7.34274 = 36.7137w$$

$$\eta = \frac{W_{net}}{W_e} \times 100 = \frac{7.34274}{16.4752} \times 100 = 44.6\ \%$$

Table 4.8: Comparison to Theory

Parameter	Theory	Test
RPM	384	300
Hot Temp (˚c)	372	278
Cold Temp (˚c)	0	0
Net Power Output (W)	80	36.7137

Table 4.8 shows the comparison between theory and testing performance of the engine. The variation of friction and heat transfer makes it difficult to get the engine to run consistently at prescribed conditions. These results occur because of the fact that the actual heat requirement of the cycle is much lower than the total stored energy. Also, the hot cylinder continued to heat up as the engine was operating which indicates that there was sufficient heat transfer input to keep the engine running.

4.4 Discussion

The prototype of stirling engine has been fabricated successfully without any major problems and follows several identified criterion such as easy to fabricate and low cost in long term. The process to fabricate this prototype of stirling engine has been done on time although there are several technical problems such as machines usage problems, problem with cutting tool and the part matching problems. But after the problems were solved the fabrication was completed. Detail causes of these technical problems are discussed below.

The first problem is the flywheel support is not rigid and causing the wheel to wobble slightly. The flywheel support must be very rigid to the piston rod so that it can function to create pressure and heat transfer. The problem was overcome by redesign the flywheel and fabricate for more rigid flywheel support.

The second problem, early assemble the stirling engine can't move. It is because many frictions occur inside out of the surface piston rod and also connector rod. When many frictions happen, pressures required to move the piston is too big. To solve the problem the connector piston and piston rod were readjusted. Lubrication oil was applied on the components.

Last technical problem occur is assemble. After problem solving section, there is some reason that causes for this problem. The major causes come from fabrication of the part. The dimensions and the tolerance of part must explain clearly and detail because small error will give big effect to the part. The other cause is come from machinery, cutting tool and technique to fabricate the part. To fabricate the part with detail tolerance, the suitable machine, cutting tool and technique must be select correctly. All those problems were overcome by rework.

In conclusion, the important factor to design and fabricate the perfect prototype of stirling engine is base on the selection of material and it`s fabrication process. The suitable material, corrects dimensions with detail tolerance and correct technique in fabrication will cause the stirling engine function well without any problem. If no problem appears the stirling engine would function smoothly.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Introduction

In conclusion, this project was completed according to planning and the problems arise were solved. The machine that has been developed was able to increase the efficiency and can produce the output. The design machine consideration has been done with several factors such as the concept and the fabrication. To make stirling engine function there were some factors that should be taken into consideration. For example in fabrication, the tolerance and parameter need to measure clearly. The technique was applied and machine that used in fabrication also need to be considered. A machine broke down and need maintenance. After the machine service the project can be continue to achieve the objectives.

5.2 Recommendation

There were several recommendations to make sure the stirling engine can function effectively. First the weight of the stirling engine The lighter products more easily to handle and can storage in small places.

Second, is the accuracy of fabrication. It is important in assembly section. The rigid part in fabrication will produce the accurate assemble. So the machine will function as expected. The performance of stirling engine not function well but the stirling engine can produced output with 300 rpm working speed. From the calculation with 300 rpm only can produce 36.713 watt. But in electrical equipment such as bulb need 75 watt. So, for future plan, the output of stirling engine that produced the work done must be developed and increase. Next planning need reduce the vibration of machine. The way to reduce the vibration is use a proper material and rigidity in fabrication.

Besides that, stirling engine can combine with dynamometer to produce electricity. A dynamometer is a device for measuring force, moment of force (torque), or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (RPM). A dynamometer can also be used to determine the torque and power required to operate a driven machine such as a pump. In that case, motoring or driving dynamometer is used. A dynamometer that is designed to be driven is called an absorption or passive dynamometer.

Different material of producing a stirling engine also can be used for make a new invention. Material characteristic and material properties must be analyzed precisely to make a good invention and to make stirling engine running with more power and efficient.

After this stirling engine work as expected, it`s could be commercialized and modified with adding other machine such as solar system to get the burning without using burner Bunsen. As recommendation, to solve the high cost for producing stirling engine loan can be acquired from University Malaysia Pahang (UMP). Then, this newly modified stirling engine is ready to compete with other design of stirling engine.

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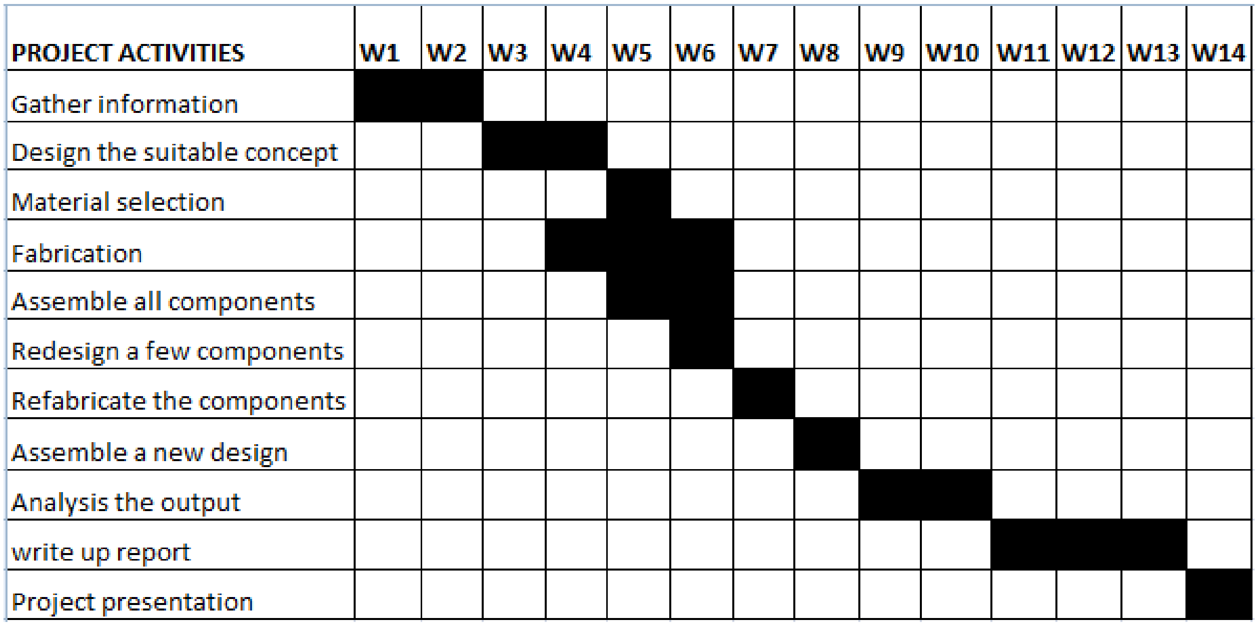
APPENDICE A

GANTT CHART FOR PSM 1 AND PSM 2



APPENDICE B

(Small Stirling Engine Orthographic Drawing)