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CONCEPTUAL STUDY, DESIGN AND ANALYSIS OF STIRLING ENGINE

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ABSTRACT

Stirling Engine is a closed-cycle regenerative heat engine with a gaseous working fluid. There are three type of stirling engine, which is Alpha, Beta and Gamma type. In this thesis, the focus is on Schmidt theory, comparison between Alpha-Type Stirling Engine and Beta-Type Stirling Engine to be selected in the design and analysis on the selected design by using finite element analysis. The Schmidt theory is one of the isothermal methods for Stirling engines. It is the most simple method and very useful during stirling engine development. This theory is based on the isothermal expansion and compression of an ideal gas. From the theory, the pressure, volume, power and efficiency of the engine has been calculate. Trough this calculation, two type of stirling engine will be compared and Alpha-Type has been chosen for the design because the result of the comparison show that Alpha-Type stirling engine produce more power compare to Beta-Type stirling engine. After choosing the type of stirling engine, finite element analysis will be tested to the engine. Type of analysis that tested to the piston of the engine is static analysis and thermal analysis.

ABSTRAK

"Stirling Engine" merupakan satu engin kitar semula tertutup dengan menegunakan gas sebagai alat untuk menggerakkannya. Terdapat tiga jenis "Stirling Engine", iaitu Alpha, Beta dan Gamma. Thisis ini bertumpu pada teori Schmidt, perbandingan antara jenis Alpha dan Beta untuk dipilih dalam merekabentuk dan jenis engin yang terpilih akan menjalani kajian unsure terhingga. Teori Schmidt merupakan salah satu kaedah isotermo untuk "Stirling Engine". Ia merupakan kaedaah yang sangat mudah dan sangat berguna semasa membuat perkembangan untuk engin jenis ini. Teori ini berdasarkan isotermo mengembangan dan mengetumpat dari idea gas. Dari teori ini, tekanan, luas permukaan, kuasa dan kecekapan engin dikira. Melalui pengiraan ini, dua jenis engin akan dibuat perbandingan dan engin jenis Alpha dipilih kerana kuasa yang dijanakan oleh jenis Alpha lebih tinggi berbanding dengan jenis Beta. Selepas pemilihan engin, analisa "finite element" akan diuji pada rekebebtuk tersebut. Jenis analisa yang diuji pada piston ialah analisis statik dan analisis termal.

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SEVEN CONCLUSION & RECOMMENDATION

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LIST OF SYMBOL

P = Engine Pressure, Pa

V_{SE} = Swept volume of expansion piston or displacer piston, m^3

V_{SC} = Swept volume of compression piston or power piston, m^3

V_{DE} = Dead volume of expansion space, m^3

V_R = Regenerator volume, m^3

V_{DC} = Dead volume of compression space, m^3

V_E = Expansion space momental volume, m^3

V = Compression space momental volume, m^3

V = Total momental volume, m^3

m = Total mass of working gas, kg

R = Gas constant, J/kgK

T = Expansion space gas temperature, K

T = Compression space gas temperature, K

T = Regenerator space gas temperature, K

[illegible] = Phase angle, deg(°)

t = Temperature ratio

[illegible] = Swept volume ratio

[illegible] = Dead volume ratio

N = Engine speed, H

W = Indicated expansion energy, J

W = Indicated compression energy, J

W = Indicated energy, J

L = Indicated expansion power, W

L = Indicated compression power, W

L = Indicated power, W

[illegible] = Indicated efficiency

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Projek Sarjana Muda (PSM) is compulsory finished up by an undergraduate student with a Bachelor holder in Mechanical Engineering field. To complete this project, a tittle is regarding the conceptual study, design and analysis of stirling engine. An opening ideal of stirling engine will be discussed in this subtitle and the details will be discussed thoroughly in Chapter 2. In the family of heat engines, 'Stirling engine' defines a closed-cycle regenerative hot air engine. In this context; "hot air" may be taken to include other permanent gases, "closed-cycle" to mean the working fluid is permanently contained within the system, and "regenerative" to refer to the use of an internal heat exchanger - the regenerator.

1.1 Problem Statement

To come out a new design of stirling engine. To completing a design on stirling engine, there are many problems to be take consideration. Nowadays, there are three types with different specification of stirling engine are designed for the uses respectively but in this project, only two type of stirling engine is consider. This two type of stirling engine is Alpha and Beta type. The comparision of this two type of stirling engine will be the design in this project. The initial consideration is the operating temperature, pressure and working medium of the stirling engine. In addition, the Schmidt theory for stirling engines should be took understanding. Once the problems are clearly stated, the process of designing a stirling engine by using motorcycle block engine will be held smoothly.

1.2 Objective

The objectives of this project are:

I. Comparison on stirling engine (Alpha stirling and Beta stirling).
II. Study and analysis the piston of stirling engine by using COSMOSWorks.
III. Design and development of mini stirling engine.
IV. Design a mini stirling engine that produce low power output.

1.3 Scope of Project

The scopes in this project are including:

I. To study Schmidt theory for stirling engines.
II. Comparison the characteristic of stirling engine.
III. To design a mini stirling engine.
IV. Doing an analysis by using Finite Element Analysis (FEA).

1.4 Thesis Outline

Thesis outline is a summary of every chapter is described to introduce about the chapter. Chapter 1 introduced about the project title which is stirling engine, problem encountered, and contents of the thesis and the objective and scope of project. Chapter 2 covers the literature review for stirling engine. Schmidt theory for Alpha and Beta type stirling engine will be describe in Chapter 3 .Next chapter is Chapter 4, it will describe the project implementation from collection data and information until the design is verified. In Chapter 5, comparison between Alpha type stirling, Beta type stirling and a simple analysis on piston will be shown.

1.5 Summary

This chapter has simply introduced the project title to be completed. In order to complete a design, problem statement must take consideration. When the problem is verify, the objective and scope of project will focus on the problem statement and then redesign a stirling engine. In order to make the report tidily, a thesis outline is added to smooth the work.

CHAPTER 2

LITERATURE REVIEW

2.0 Background

In the conversion of heat into mechanical work, the Stirling engine has the potential to achieve the highest efficiency of any real heat engine, theoretically up to the full Carnot efficiency, though in practice this is limited by non-ideal properties of the working gas and engine materials, such as friction, thermal conductivity, tensile strength, creep, melting point, etc. The Stirling engine can run on any heat source, including solar, chemical and nuclear. There are many possible implementations of the Stirling engine most of which fall into the category of reciprocating piston engine.

In contrast to internal combustion engines, Stirling engines have the potential to be more energy efficient, quieter, and more reliable with lower maintenance requirements. They are preferred for certain niche applications that value these unique advantages, particularly in cases where the primary objective is not to minimize the capital cost per unit power, but rather to minimize the cost per unit energy generated by the engine. Compared to an internal combustion engine of a given power rating, Stirling engines currently have a higher capital cost and are usually larger and heavier; therefore, the engine technology is rarely competitive on this basis alone. For some applications, a proper cost-benefit analysis can favor a Stirling engine over an internal combustion engine.

In recent years, the advantages of Stirling engines have become increasingly significant, given the general rise in energy costs, energy shortage and environmental concerns such as climate change. These growing interests in Stirling technology have fostered the ongoing research and development of Stirling devices. The applications include water pumping, space-based astronautics, and electrical generation from plentiful energy sources that are incompatible with the internal combustion engine, such as solar energy, agricultural waste and domestic refuse.

Another useful characteristic of the Stirling engine is that the cycle is reversible, meaning that if supplied with mechanical power, it can function as a heat pump. Experiments have been performed using wind power driving a Stirling cycle heat pump for domestic heating and air conditioning. In the late 1930s, the Philips Corporation of the Netherlands successfully utilized the Stirling cycle in cryogenic applications.

2.0.1 History

Stirling's air engine was invented by Reverend Dr. Robert Stirling and patented by him in 1816. It followed earlier attempts at making an air engine and it was probably the first to be put to practical use when in 1818 an engine built by Stirling was employed pumping water in a quarry. When the name became simplified to Stirling engine is not known, but may be as recently as the mid twentieth century when the Philips company began to experiment with working fluids other than air. The main subject of Stirling's original patent was a heat exchanger which he called the "economiser" for its enhancement of fuel economy in a variety of applications. The patent also described in detail the employment of one form of the economiser in an air engine, in which application it is now commonly known as a regenerator. Subsequent development by Robert Stirling and his brother James, an engineer, resulted in patents for various improved configurations of the original engine, including pressurisation which by 1845 had sufficiently increased the power output for it to drive all the machinery at a Dundee iron foundry.

As well as conserving fuel, the inventors sought to create a safer alternative to the steam engines of the time whose boilers frequently exploded with dire consequences. The need for Stirling engines to run at very high temperatures to maximize power and efficiency exposed limitations in the materials of the day and the few engines that were built in those early years suffered unacceptably frequent failures.

Though it failed as a competitor to the steam engine as an industrial scale prime mover, during the latter nineteenth and early twentieth century's smaller engines of the Stirling/hot air type were produced in large numbers, finding application wherever a reliable source of low to medium power was required, such as raising water. These generally operated at lower temperatures so as not to tax available materials, and thus tended to be rather inefficient. Their major selling point was that they could be operated safely by anybody capable of managing a fire. As the century progressed, this role was eventually usurped by the electric motor and small internal combustion engines, and by the late 1930s the Stirling engine was a largely forgotten scientific curiosity represented only by toys and a few small ventilating fans.

At this time Philips wanted to expand sales of its radios in areas where mains electricity was unavailable and the supply of batteries uncertain. Philips' management decided that a low-power portable generator was needed, and tasked a group of engineers at the company research lab (the Nat. Lab) in Eindhoven to evaluate the situation. Reviewing various prime movers, each was rejected until the Stirling engine was considered. Inherently quiet and capable of running from any heat source (common lamp oil was favoured), it seemed promising. Encouraged by their first experimental engine, which produced 16 watts of shaft power from a bore and stroke of 30x25mm, a development program was begun. This work continued throughout World War II and by the late 1940s they had an engine – the Type 10 – which was sufficiently developed to be handed over to Philips' subsidiary Johan de Witt in Dordrecht to be 'productionised' and incorporated into a generator set. The set progressed through three prototypes (102A, B, and C), with the production version, rated at 200 watts electrical output from a bore and stroke of 55x27 mm, being designated MP1002CA (known as the 'Bungalow set'). Production of an initial batch began in 1951, but it became clear that they could not be made at a price that the market would support, and the advent of transistor radios with their much lower power requirements meant that the whole raison d'être for the set was disappearing. Though the MP1002CA may have been a dead end, it represents the start of the modern age of Stirling engine development.

Philips went on to develop the Stirling engine for a wide variety of applications including vehicles, but only achieved any commercial success with the 'reversed Stirling engine' cryocooler. They did take out a large number of patents and amass a wealth of information relating to Stirling engine technology, which was later licensed to other companies.
(en.wikipedia.org/wiki/Stirling_engine (2008))

2.1 Functional Description

2.1.1 The Engine Cycle

Since the Stirling engine is a closed cycle, it contains a fixed mass of gas called the "working fluid", most commonly air, hydrogen or helium. In normal operation, the engine is sealed and no gas enters or leaves the engine. No valves are required, unlike other types of piston engines. The Stirling engine, like most heat-engines, cycles through four main processes: cooling, compression, heating and expansion. This is accomplished by moving the gas back and forth between hot and cold heat exchangers. The hot heat exchanger is in thermal contact with an external heat source, such as a fuel burner, and the cold heat exchanger being in thermal contact with an external heat sink, such as air fins. A change in gas temperature will cause a corresponding change in gas pressure, while the motion of the piston causes the gas to be alternately expanded and compressed.

The gas follows the behavior described by the gas laws which describe how a gas's pressure, temperature and volume are related. When the gas is heated, because it is in a sealed chamber, the pressure rises and this then acts on the power piston to produce a power stroke. When the gas is cooled the pressure drops and this means that less work needs to be done by the piston to compress the gas on the return stroke, thus yielding a net power output.

When one side of the piston is open to the atmosphere, the operation is slightly different. As the sealed volume of working gas comes in contact with the hot side, it expands, doing work on both the piston and on the atmosphere. When the working gas contacts the cold side, the atmosphere does work on the gas and "compresses" it. Atmospheric pressure, which is greater than the cooled working gas, pushes on the piston.

To summarize, the Stirling engine uses the temperature difference between its hot end and cold end to establish a cycle of a fixed mass of gas expanding and contracting within the engine, thus converting thermal energy into mechanical power. The greater the temperatures difference between the hot and cold sources, the greater the potential Carnot cycle efficiency.

Small demonstration engines have been built which will run on a temperature difference of as little as 7 °C, for example between the palm of a hand and the surrounding air, or between room temperature and melting water ice.

2.1.2 Pressurization

Most high performance Stirling engines are pressurized. That is, the mean pressure of the working fluid is above atmospheric pressure. This increases the mass of working fluid processed per cycle. Thus, all other things being equal, the engine produces more power. Unfortunately all other things seldom are equal, and to realise the potential of pressurization larger heat exchangers (including the regenerator) are required. This inevitably increases dead space and possibly gas flow resistance, both of which tend to reduce power output. Like most aspects of Stirling engine design, optimization of this aspect is a delicate balancing act between often conflicting requirements. It was experimenting with pressurization which initially led Philips to move from atmospheric air to other gases for the working fluid. At high temperatures and pressures, the oxygen in air tended to combine with any lubricating oil that made its way past the piston seals, giving problems with clogging the heat exchangers or even the possibility of an explosion. It was later found that some gases, particularly hydrogen and helium, offered other advantages over air.
(en.wikipedia.org/wiki/Stirling_engine (2008))

2.2 Engine Configurations

Engineers classify Stirling engines into three distinct types. The Alpha type engine relies on interconnecting the power pistons of multiple cylinders to move the working gas, with the cylinders held at different temperatures. The Beta type Stirling engines use a displacer piston to move the working gas back and forth between hot and cold heat exchangers in the same cylinder.