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

Signature : ....

Name of Supervisor : Mr. Safarudin Gazali Herawan

Date : 30.05.2006

© Universiti Teknikal Malaysia Melaka

THE DEVELOPMENT OF SOLAR ENERGY COLLECTOR FOR STIRLING ENGINE TO OBTAIN AN OPTIMUM PRODUCED POWER

ABDUL RAUF BIN ABDUL KADIR

This thesis is submitted to Mechanical Engineering Faculty in partial fulfillment of the requirements for the award of Bachelor Degree in Mechanical Engineering (Thermal-Fluid)

Faculty of Mechanical Engineering
Kolej Universiti Teknikal Kebangsaan Malaysia

May 2006

© Universiti Teknikal Malaysia Melaka

"I hereby declare that this thesis entitled 'The development of solar energy collector for Stirling engine to obtain an optimum produced power' is the result of my own research except as cited in the references"

Signature : ....

Name : Abdul Rauf Bin Abdul Kadir

Date : 30 . 05 . 2006

© Universiti Teknikal Malaysia Melaka

Specially dedicated to my beloved family,

Mr. Abdul Kadir Haji Talib

Mrs. Sabariah Othman

Mr. Khairul Nizam Abdul Kadir

Mr. Anwar Abdul Kadir

Mr. Abdul Razak Abdul Kadir

Mr. Abdul Hakim Abdul Kadir

Not forgetting my supervisor, Mr. Safarudin Gazali Herawan, all my companions and my one and only dear friend Nur Ayuni and her family. A million thanks for giving me precious inspiration and lifelong encouragement…

Faculty of Mechanical Engineering, KUTKM

© Universiti Teknikal Malaysia Melaka

ACKNOWLEDGEMENT

Assalamualaikum W.B.T.

Alhamdulillah. All the praise for Allah The Mighty. With the blesses giving me the strength and inspiration to complete this thesis. Firstly, I would like to express my gratitude to my project Supervisor Mr. Safarudin Gazali Herawan. Thanks a lot for the guidance and supports and sharing knowledge during the completion of this thesis.

It is my pleasure and gratitude to express my special thanks to all Thermodynamic Lab technicians especially to Mr. Asjufri for the assistance to guide me in experiment process for this project. Also, not forget thanks to all the lecturers of KUTKM for the knowledge that you all have taught me since 4 years I have been here. Last but not least a special warm and grateful appreciation to my parent and friends for the support and encouragement to undergo this project.

Finally, I would like to express my highest sincere thanks again to all that had contributed their guidance and help upon completion of this project.

Thank you…..

© Universiti Teknikal Malaysia Melaka

ABSTRACT

The development of solar energy collector for Stirling engine is a research to develop a solar energy collector with using multiple material as a medium of solar energy collector .A solar energy collector is a device for extracting the energy of the sun directly into a more usable or storable form. The energy in sunlight is in the form of electromagnetic radiation from the infrared to the ultraviolet wavelengths. The solar energy collector striking the earth's surface at any one time depends on conditions and your location on the surface. A solar energy collector for Stirling engine is a new idea to generate an optimum power for Stirling engine. This solar energy collector is a new medium to change the heat source from the available medium like alcohol and petrol burning. With using the solar energy collector it can compared between using different material as a solar energy collector. So many types of material can extract the energy of sun, like stainless steel, aluminium foil, plastic film and glass reflector. The results also can show the comparison between using different materials for solar energy collector to generate the Stirling engine to optimum produced power. At the end of this thesis showed the material like stainleess steel, aluminium, plastic film and glass reflector can be used as a basic material for solar energy collector to generate Stirling engine to optimum level power produced.

© Universiti Teknikal Malaysia Melaka

ABSTRAK

Pembangunan pemungut tenaga solar untuk enjin Stirling adalah suatu penyelidikan dalam membangunkan pemungut tenaga solar menggunakan beberapa bahan yang berbeza sebagai satu perantaraan kepada pemungut tenaga solar.Pemungut tenaga solar adalah satu alat yang berfungsi sebagai pemantul tenaga matahari terus kepada bentuk yang lebih berguna untuk menyimpan haba.Tenaga dalam cahaya matahari adalah dalam bentuk pemancaran elektromagnetik daripada inframerah kepada gelombang panjang ultraviolet. Pemungut tenaga solar mencolok ke arah permukaan bumi pada setiap masa bergantung kepada keadaan dan kedudukan kita pada permukaan. Pemungut tenaga solar untuk enjin Stirling adalah idea baru dalam menghasilkan kuasa yang terbaik bagi enjin Stirling. Pemungut tenaga solar ini bertindak sebagai perantaran baru bagi menggantikan punca kepanasan daripada perantaraan sediakala seperti pembakaran alkohol dan petrol. Dengan menggunakan pemungut tenaga solar ini, akan dapat membandingkan di antara penggunaan bahan yang berlainan sebagai pemungut tenaga solar. Beberapa jenis bahan dapat memantulkan kekuatan daripada matahari seperti keluli tahan karat, kerajang aluminium, plastik filem dan kaca pemantul. Di dalam keputusan didapat perbandingan antara menggunakan bahan yang berlainan untuk pemungut tenaga solar bagi menggerakkan enjin Stirling ke tahap yang lebih baik bagi kuasa yang dihasilkan. Di akhir tesis ini, akan menunjukkan penggunaan bahan seperti keluli tahan karat, kerajang aluminium, plastik filem dan kaca pemantul boleh digunakan sebagai bahan asas kepada pemungut tenaga solar untuk menggerakkan enjin Stirling kepada tahap yang lebih baik dalam penghasilan kuasa.

© Universiti Teknikal Malaysia Melaka

TABLE OF CONTENTS

© Universiti Teknikal Malaysia Melaka

© Universiti Teknikal Malaysia Melaka

© Universiti Teknikal Malaysia Melaka

© Universiti Teknikal Malaysia Melaka

LIST OF TABLES

© Universiti Teknikal Malaysia Melaka

LIST OF FIGURES

© Universiti Teknikal Malaysia Melaka

© Universiti Teknikal Malaysia Melaka

LIST OF SYMBOL

SYMBOL	DEFINITION
V	Volume
p	Pressure
T	Temperature
Q	Thermal energy
W	Work
Δt	Time duration
ρ	Density
M	Torque
P	Power
f	Frequency
A	Area
C	Geometrical concentration ratio
n	Rotation speed

GREEK	DEFINITION
η	Efficiency

SUBSCRIPT	DEFINITION
LTD	low temperature differential
RPM	Revolution per minute

© Universiti Teknikal Malaysia Melaka

LIST OF APPENDIX

© Universiti Teknikal Malaysia Melaka

CHAPTER I

INTRODUCTION

1.1 Overview

Solar energy is an attractive renewable energy source that can be used as an input energy source for heat engines. In fact, any heat energy source can be used in a Stirling engine. The solar radiation can be focused onto the displacer hot end of the Stirling engine, thereby creating a solar powered prime mover. The direct conversion of solar power into mechanical power reduces both the cost and complexity of the prime mover. When a solar energy collector is used as a heat input source of a heat engine for power generation, one of the design objectives is to optimize the overall system performance. In general, the collector works best at low temperature (Kongtragool B, Wongwises.S, 2003) and its efficiency decreases with increasing temperature. However, the heat engine is most efficient with heat input at high temperatures and its efficiency increases with increasing temperature. The overall efficiency of the direct solar powered heat engine is the product of the solar energy collector efficiency and the heat engine efficiency. The optimum solar energy collector for Stirling engine has been studied by many researches (Kongtragool B, Wongwises.S, 2005). Among many researches, some closely related works are to determine the optimum value of the outlet temperature of the solar energy collector to optimum the work output produced of idealized Stirling, Carnot, Ericsson and Bryton engines powered by a solar energy collector.

© Universiti Teknikal Malaysia Melaka

1.2 Objectives of the project

Objective of this thesis is to develop the solar energy collector for Stirling engine. For this project the interest is to compare the available Stirling engine solar collector at Thermodynamics Lab with another one that be developed can obtain more produced power. This project will give a benefit to the reader especially at an introduction level. Also, this thesis could be a beginning for the further study in Stirling engine field using a solar energy collector based from several materials for solar energy collector.

1.3 Scopes of the project

The scopes of this thesis are as follow:

- Study the Stirling engine.
- Study on solar energy collector.
- Conducts the experiment using Stirling engine generates by solar energy.

1.4 Gantt chart

The progress of the project was shown in **Appendix D** and **Appendix E**.

© Universiti Teknikal Malaysia Melaka

CHAPTER II

LITERATURE REVIEW

2.0 Stirling engine history

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; its ability to use any burnable material as fuel, its safe, quiet, moderately efficient operation, and its durability and low maintenance requirements. It was very large for its small power output, however, and had 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. The other major disadvantage of the early hot-air engine was its tendency to fail if the heater head got too hot. This as a result of the relatively low heat resistance of the cast iron heater head (Walker G, 1980).

The problem was overcome by redesigning the burner, which prevented the engine from over heating. This improvement resulted in safe, but even lower, power operation. Despite this improvement, the Stirling engine could not compete with the

© Universiti Teknikal Malaysia Melaka

powerful internal combustion engine, and it disappeared from the commercial scene. The advent of newer stainless steels and advances in the understanding of the engine's complex thermodynamic process brought new attention to the engine during and after World War II. The performance of the old hot-air engine was improved and its size and cost were reduced. Its simplicity of construction and operation, and most important, its ability to use rough fuels were retained. These efforts on Stirling engines were almost exclusively aim that difficult application that were not appropriate for developing countries namely, the advanced automotive engine, space power and artificial hearts. Almost no effort was put into the relatively easy task of designing an engine for ordinary uses. The highly developed countries in which the Stirling engine work was being done did not need a simple engine, so there was no economic incentive to design one. 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 manufacture in simple machine shops of the type found in many regions of Africa, Asia and Latin America.

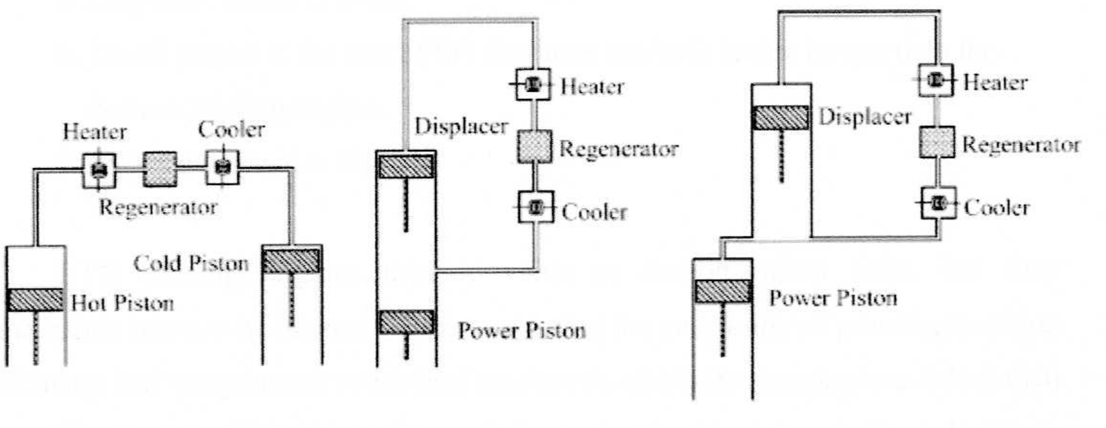
2.1 Introduction to Stirling engine

2.1.1 General principles

Stirling engines are mechanical devices working theoretically on the Stirling cycle, or its modifications, in which compressible fluids, such as air, hydrogen, helium, nitrogen or even vapors, are used as working fluids. The Stirling engine offers possibility for having high efficiency engine with less exhaust emissions in comparison with the internal combustion engine. The earlier Stirling engines were huge and inefficient. However, over a period of time, a number of new Stirling engine models have been developed to improve the deficiency. The modern Stirling engine is more efficient than the early engines and can use any high temperature heat source. The Stirling engine is an external combustion engine. Therefore, most sources of heat can power it, including combustion of any combustible material, field

© Universiti Teknikal Malaysia Melaka

pistons, are used on either side of the heater, regenerator, and cooler. These pistons move uniformly in the same direction to provide constant-volume heating or cooling processes of the working fluid. When all the working fluid has been transferred into one cylinder, one piston will be fixed and the other piston moves to expand or compress the working fluid. The expansion work is done by the hot piston while the compression work is done by the cold piston. In the beta-configuration, a displacer and a power piston are incorporated in the same cylinder. The displacer moves working fluid between the hot space and the cold space of the cylinder through the heater, regenerator, and cooler. The power piston, located at the cold space of the cylinder, compresses the working fluid when the working fluid is in the cold space and expands the working fluid when the working fluid is moved into the hot space. The gamma-configuration uses separated cylinders for the displacer and the power pistons, with the power cylinder connected to the displacer cylinder. The displacer moves working fluid between the hot space and the cold space of the displacer cylinder through the heater, regenerator, and cooler. In this configuration, the power piston both compresses and expands the working fluid. The gamma-configuration with double-acting piston arrangement has theoretically the highest possible mechanical efficiency. This configuration also shows good self-pressurization. However, the engine cylinder should be designed in vertical type rather than horizontal in order to reduce bushing friction.



(a) The Alpha configuration (b) The Beta configuration (c) The gamma configuration

Figure 2.1: Basic configurations for Stirling engine

© Universiti Teknikal Malaysia Melaka

waste, rice husk or the like, biomass methane and solar energy. In principle, the Stirling engine is simple in design and construction, and can be operated easily. Direct solar-powered Stirling engines may be of great interest to countries where solar energy is available in unlimited quantity. To use direct solar energy, a solar concentrator and absorber must be integrated with the engine system. The Stirling engine could be used in many applications and is suitable where (Van Arsdell BH, 2001):

1) multi-fueled characteristic is required,
2) A very good cooling source is available,
3) Quiet operation is required,
4) Relatively low speed operation is permitted,
5) Constant power output operation is permitted,
6) Slow changing of engine power output is permitted,
7) A long warm-up period is permitted.

2.2 Stirling engine configurations

2.2.1 Mechanical configurations of the Stirling engine

Various machine components have been combined to provide the Stirling cycle. The cycle provides a constant-volume process during the transfer of working fluid between the hot and cold space of the engine, and provides a constant temperature heating and cooling process during compression and expansion. The compression and expansion processes of the cycle generally take place in a cylinder (called power cylinder) with a piston (called power piston). A displacer piston (simply called displacer) shuttles the working fluid back and forth through the heater, regenerator, and cooler at constant volume. A displacer that moves to the cold space displaces the working fluid from the cold space causing it to flow to the hot space and vice versa. Three different configurations, namely the **alpha**, **beta** and **gamma** configurations, refer **Figure 2.1** are commonly used. Each configuration has the same thermodynamics cycle but has different mechanical design characteristics. In the alpha-configuration a displacer is not used. Two pistons, called the hot and cold

© Universiti Teknikal Malaysia Melaka

2.2.2 Low temperature differential engine configuration

A low temperature differential (LTD) Stirling engine can be run with small temperature difference between the hot and cold ends of the displacer cylinder (Rizzo JG, 1997). It is different from other types of Stirling cycle engines, which have a greater temperature difference between the two ends, and therefore the power developed from the engine can be greater. LTD engines may be of two designs. The first uses single-crank operation where only the power piston is connected to the flywheel, called the Ringbom engine. This type of engine, that has been appearing more frequently, is based on the Ringbom principle. A short, large-diameter displacer rod in a precise-machined fitted guide has been used to replace the displacer connecting rod. The other design is called a kinematics engine, where both the displacer and the power piston are connected to the flywheel. The kinematics engine with a normal 90° phase angle is a gamma configuration engine.
Some characteristics of the LTD Stirling engine are as follows (Rizzo JG, 1997):

1. Displacer to power piston swept volumes ratio is large.
2. Diameter of displacer cylinder and displacer is large.
3. Displacer is short.
4. Effective heat transfer surfaces on both end plates of the displacer cylinder are large.
5. Displacer stroke is small.
6. Dwell period at the end of the displacer stroke is rather longer than the normal Stirling engine.
7. Operating speed is low.

LTD Stirling engines provide value as demonstration units, but they immediately become of interest when considering the possibility of power generation from many low temperature waste heat sources in which the temperature is less than 100°C (Van Arsdell BH, 2001). A calculation using the Carnot cycle formula shows that an engine operating with a source temperature of 100°C and a sink temperature of 35°C gives a maximum thermal efficiency of about 17.42%. If an engine could be built for achieving 50% of the maximum thermal efficiency, it would have about 8.71% overall Carnot efficiency. Even the calculated thermal efficiency seems rather

© Universiti Teknikal Malaysia Melaka

low, but LTD Stirling engines could be used with free or cheap low temperature sources. This engine should be selected when the low cost engines are put into consideration. Although the specific power developed by LTD Stirling engines is low, lightweight and cheap materials such as plastics can be used as engine parts.

2.3 Stirling engine operations

2.3.1 Theory

Stirling engines are very different from the common internal combustion engines found in most present day vehicles. Stirling engines do not require the use of fossil fuels and therefore can be used without producing harmful waste products. They can use solar energy or waste energy from other sources to produce power. The Stirling cycle is a heat addition and heat dissipation process just like the well-known Carnot cycle. Heat addition comes from the high temperature reservoir, T_H, and then later in the cycle, heat is rejected to the low temperature reservoir, T_L. In our Stirling engine, the high temperature reservoir is provided by the sun's solar energy. During the heat addition and rejection stages, the ideal Stirling cycle is a constant temperature process. During the other two stages of the cycle, a regenerator causes an increase in temperature while volume remains constant within the system.

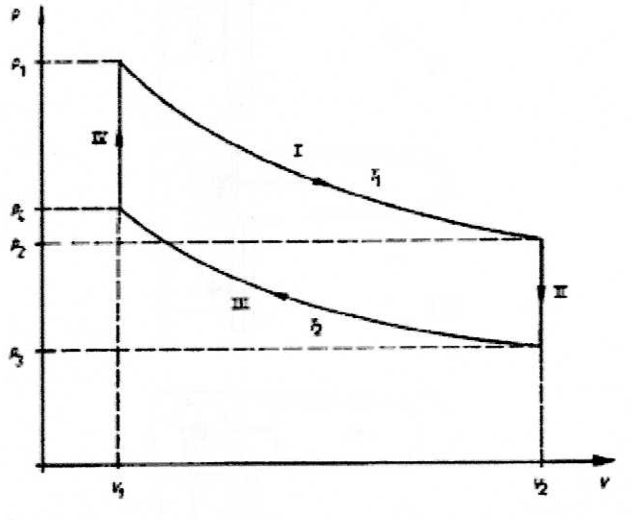


Figure 2.2: *pV* diagram for the ideal Stirling process.

© Universiti Teknikal Malaysia Melaka