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Analysis and Fabrication of Solar Stirling Engines

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Abstract: **The performance of Stirling engines (alpha type) meets the demands of the efficient use of energy and environmental security and hence they are the subject of current interest. Hence, many scientific institutes and commercial companies are now focussing on the development and investigation of Stirling engine. The Stirling engine is both practically and theoretically a significant device. The aim of this project is to provide fundamental information and present a detailed review of the efforts taken by for the development of the Stirling cycle and techniques used for engine analysis. A number of attempts have been made to build and improve the performance of Stirling engines. It is seen that for successful operation of engine system with better efficiency, design should be carefully made. Proper selection of drive mechanism and engine configuration is essential. This project indicates that a Stirling cycle engine working with relatively low temperature with air or helium as working fluid is potentially attractive engines of the future. The model is created by cero parameter1.0 (ProE) and animation is done by also this software.**

Keywords: **Engine Analysis, Fabrication of Solar Stirling Engines.**

1. INTRODUCTION

Stirling engine is an example of broad class of heat engines which are devices designed to convert thermal energy into mechanical motion by cyclic compression and expansion of air or other gas, the working fluid, in a closed thermodynamic cycle at different temperature levels such that there is a net conversion of heat energy to mechanical work.

The Stirling engine uses an external heat source to heat the working substance. The heat source can come from burning non renewable source of energy, or whatever is available. In fact, all the Stirling engine requires a temperature difference for operation. It is possible to run a Stirling engine by cooling one region of the engine below ambient temperature. The gas inside the cylinder of a Stirling engine is not burned or consumed in anyway. Hence, compared to the internal combustion engine, the Stirling engine does not require an exhaust or an intake. If the external heat source used is clean with the Stirling engine, it can be a possible environmental friendly alternative to engines that emit hydrocarbon pollutants.

Stirling engines also reduces noise pollution because they do not require intake and exhaust valves which is the main source of engine noise. However, Stirling engines that can be used for automobile use would be larger, heavier, and more expensive than conventional internal combustion engines. Moreover, Stirling engines require warm up time before they starts ,however the output of the engine cannot be changed quickly for quick acceleration and retardation.

Although Stirling engines have not yet found use in the automotive industry. Recently, there has been an interest in Stirling engines as more fuel efficient and clean engines are demanded. The engine has been the source of interest over decades because the theoretical efficiency is calculated to be nearly equal to its theoretical maximum efficiency

2. LITERATURE REVIEW

This literature review covers the relevant literature for mathematical models of Stirling refrigerators. Even though the operation of the Stirling refrigerator differs from that of the ideal Stirling cycle, some researchers rely on the latter for their studies. Wu et al. and Kaushik and Kumar used a finite time thermodynamic analysis of Stirling machines. The ideal cycle is assumed to be partial or complete, any analysis of the refrigerator shifts from the actual physics of occurrence during operation. In their review, Chakravarthy et al.classified the Stirling refrigerator as a periodic refrigeration system, which indicates that the pressure and flow rate in the refrigerator fluctuate periodically. Thom bare and Verma provided a thorough review of the work done on Stirling cycle-based machines. Although the review focused on engines, the analysis of the departure of Stirling machines from the ideal Stirling cycle remains relevant. Waele provided a comprehensive overview of Stirling cryocoolers and other thermal machines. Tekin and Ataer looked at improving the design of a V-type Stirling cycle refrigerator in a previous model by Ataer and Karabulut using a thermodynamic approach. Chen and Yan developed a model for a Stirling refrigerator that investigated the effects of non-ideal regenerators. Erbay and Yavuz took a more practical approach to the analysis of Stirling refrigerators by studying the cooling load per unit volume. Omari compared the differences between the ideal and real Stirling cycles that occur in the refrigerator, but lacked analysis of the affect of system parameters on performance.

3. WORKING PRINCIPLE

This Stirling engine is a typical heat engine that operates by cyclic compression and expansion of air at different temperature levels.

The lamb heats the glass tube causing the piston to be pushed out, allowing the air to flow into the cylinder. Later cooling is done by the alloy fins which in turn push the metal piston to complete the cycle

i. One side of the piston is continuously heated while the other side is continuously cooled.

ii. First the air moves to the hot side, where it heated and it expands pushing up on a piston.

iii. Then the air moves through the regenerator towards the cold side, where it gets cooled off and contract, pulling down on the piston.

iv. Temperature change inside the engine produces required pressure change to push on the piston and make the engine run.

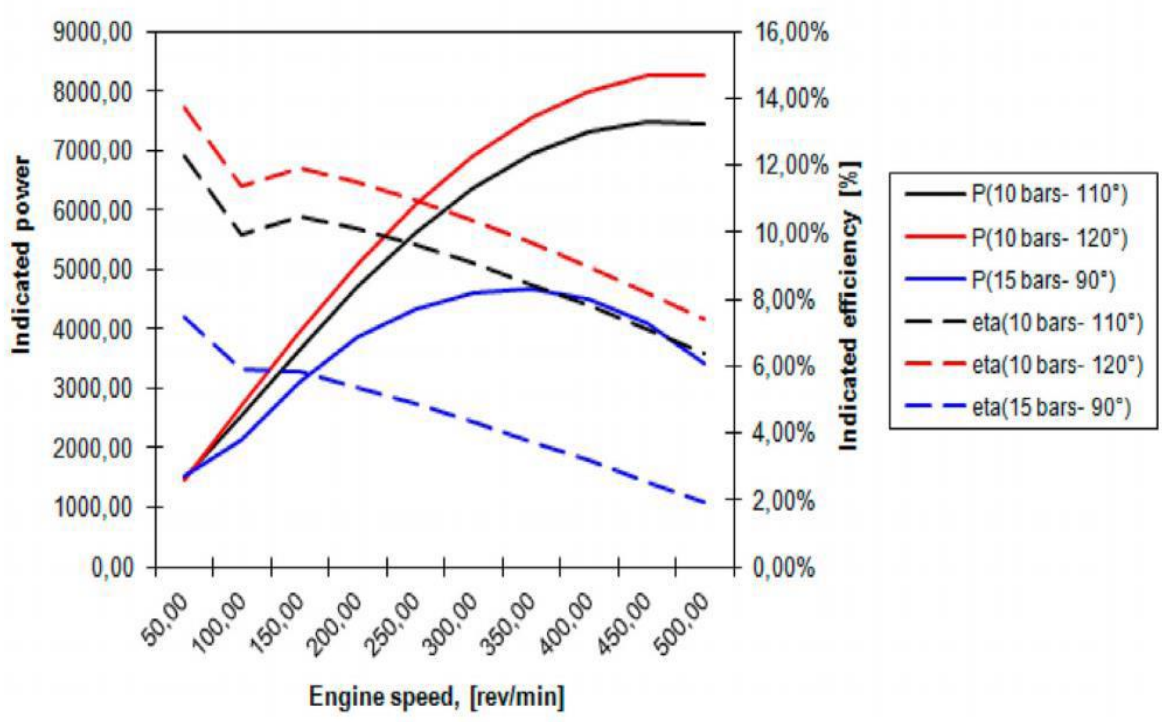

Figure 1: Performance Curve

4. OPERATING PRINCIPLES OF STIRLING ENGINE

Stirling engine consists of a cylinder that contains gas, a piston and a displacer. The regenerator and a flywheel are other main parts of the engine. When heat part of cylinder is heated up by an external heat source, the temperature rise and gas expansion is proportional to the temperature of the heat side. Total volume is kept constant and is maintained by a piston, thus the expanded gas keeps pushing the piston down, so the volume of the pressured gas is increased and the gas loses its temperature and pressure, then the piston moves back to the heat side and compresses the gas by momentum force of the flywheel, when it reaches near its upper limit the displacer pushes the cooled off gas to the heat side of the cylinder so that the gas is compressed and it is prepared to do another cycle. Thus expanded gas pushes the piston down again so as to produce mechanical energy for doing work, this cycle continues till an external heat source is available for work. The flywheel and the regenerator have immense contribution towards the engine's performance. The fly-wheel converts the linear motion of a working piston to rotary motion; it gives the required momentum for the cycle procedure. Regenerator derives heat from gas in the expansion phase and releases heat to the gas in the compression phase, thereby improving the engine's efficiency considerably. A Stirling engine and its components are shown in below.

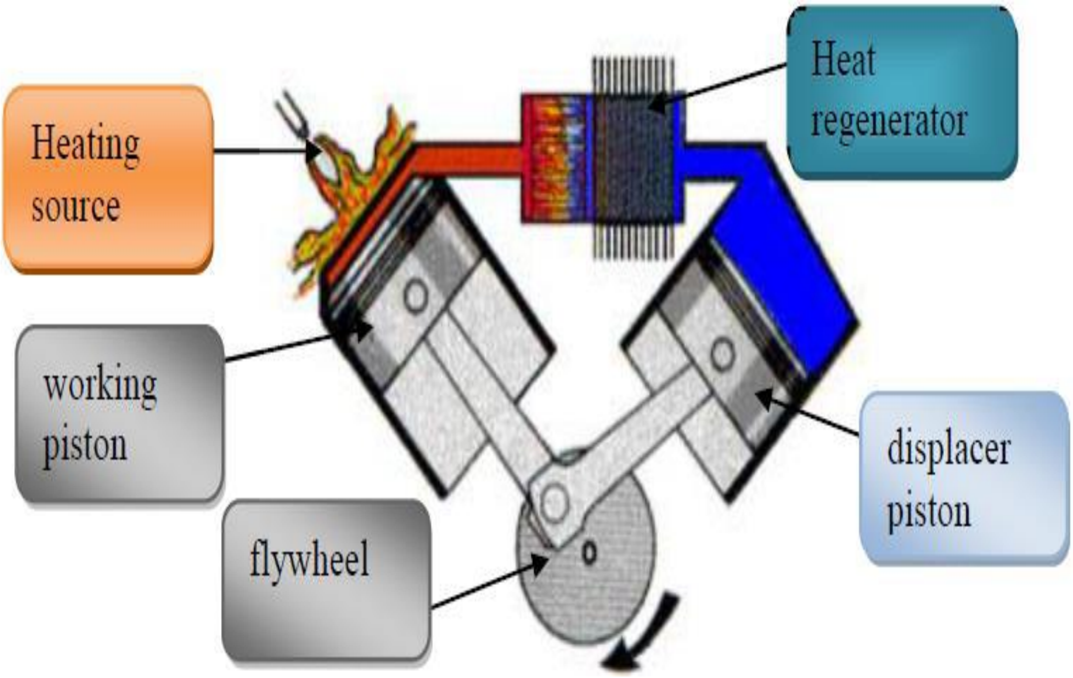

Figure 2: Stirling engine working principle

Stirling engine's working cycle has four phases; heating, expansion, cooling and Compression.

1. Heating:

Heat source provides thermal energy to the engine so that pressure and temperature of gas is raised.

2. Expansion:

In this phase the volume increases, but the pressure and temperature is decreased, mechanical energy is produced from heat energy during this phase of cycle.

3. Cooling:

The gas is cooled followed by temperature and pressure decreases, so the gas is prepared to be compressed during this cycle.

4. Compression:

The pressure of gas increases whereas its volume decreases; part of mechanical energy produced is used for processing of this phase, as it needs an amount of work to be done.

The procedure of phase can be illustrated graphically in a PV diagram as it is shown in.

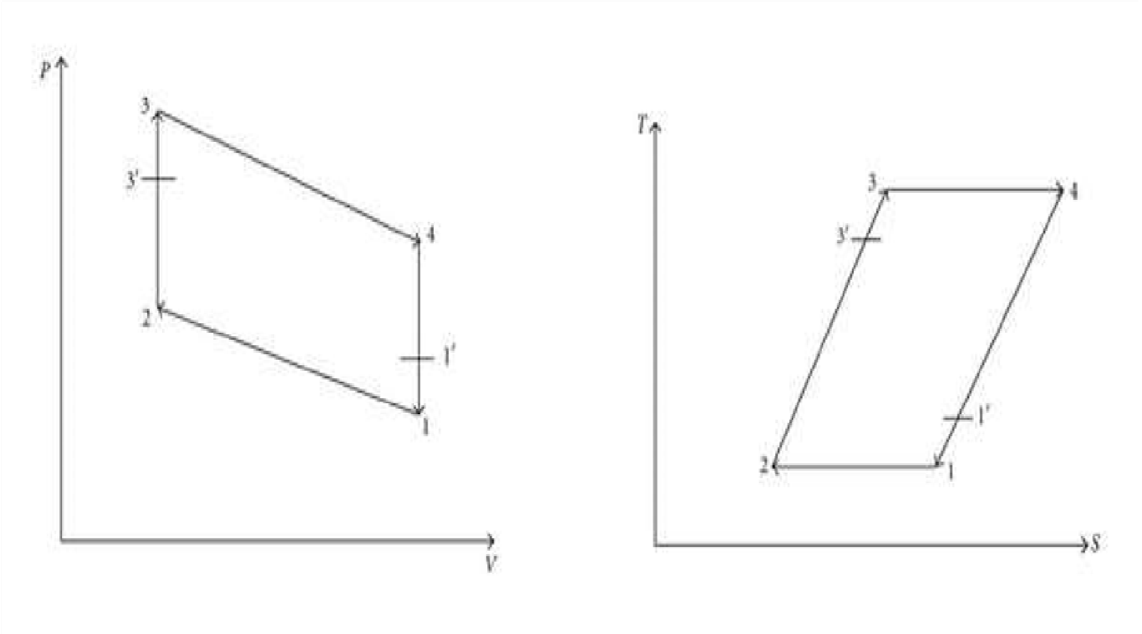

Figure 3: PV diagram and TS diagram

Looking at the graph of Stirling cycle one can see that, the volume is constant in heating phase (1-2) and cooling phase (3-4) while during Expansion (2-3) and Compression (4-1) volume is varying but temperature is constant.

The Stirling engine approximates the idealized thermodynamic process shown in Figure above, known as the Stirling cycle:

1. Process 1-2: Isothermal compression. One piston compresses the working fluid within the compression volume, while the other is stationary. This increases the pressure of the system at a constant temperature.

2. Process 2-3: Isochoric transfer I. Both pistons move in opposition (90° out of phase) to transfer the working fluid from compression to expansion volume. The regenerator, in an ideal situation, raises the fluid temperature to 3' using heat stored from process 4-1.

External heat supplies the remainder.

3. Process 3-4: Isothermal expansion. The expansion piston is moved by the expanding fluid, which is maintained at a constant temperature by the external heat source. Work is done in this stage on the piston by the working fluid.

4. Process 4-1 Isochoric transfer II. The reverse process of 2-3, both pistons work to transfer the fluid from the expansion to the compression space. The regenerator absorbs heat from the fluid, reducing the fluid temperature to that at 1'.

5. CONFIGURATIONS

There are three main types of Stirling engines that are distinguished by the way they move the air between the hot and cold areas:

5.1. The alpha configuration

5.2. The beta configuration

5.3. The gamma configuration

5.1 The alpha configuration:

There are two cylinders.

i. The expansion cylinder (red) is maintained at a high temperature.

ii. While the compression cylinder (blue) is cooled.

iii. The passage between the two cylinders contains the regenerator

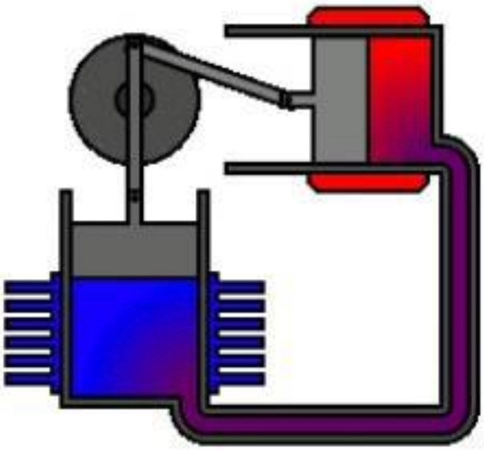

Figure 4: Alpha type

5.2 Beta type Stirling engine:

i. There is only one cylinder, hot at one end and cold at the other.

ii. A loose fitting displacer shunts the air between the hot and cold ends of the cylinder.

iii. A power piston at the end of the cylinder drives the flywheel

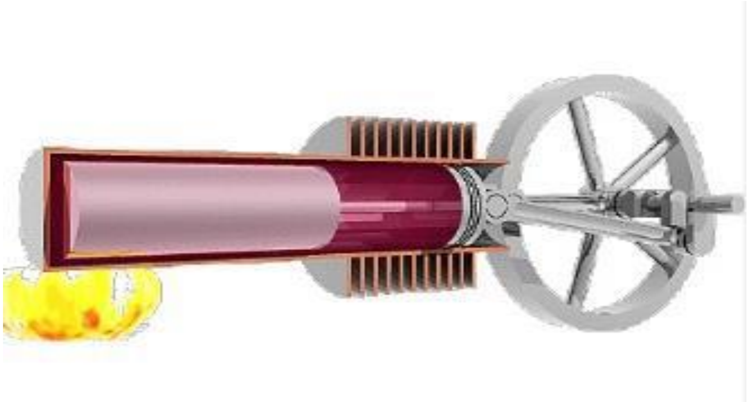

Figure 5: Beta type

5.3 The gamma configuration:

The Stirling gamma configuration is simply a Stirling beta engine in which the power piston is hot mounted coaxially with the displacer piston but in a separate cylinder.

This avoids the complications of the of the displacer piston linkage passing through the power piston.

6. EFFICIENCY

Theoretically:

i. Stilling engine efficiency = Carnot efficiency

ii. Unfortunately working fluid or gas is not ideal this results in the efficiency to be lower than Carnot efficiency.

In fact, Stirling engine efficiency depends on

i. Temperature ratio (proportionally)

ii. Pressure ration (inversely proportional)

iii. Specific heat ratio (inversely proportional)

6.1 Working fluids for Stirling engine:

Any working fluid having high specific heat capacity may be used for Stirling cycle engine. The engines of 19th century used air as a working fluid. Most of them operated close to atmospheric pressure. Since air was readily available and cheap.The working fluid in a Stirling engine should have following thermodynamic, heat transfer and gas dynamic properties.

i. High thermal conductivity

ii. High specific heat capacity

iii. Low viscosity

iv. Low density

7. CONCLUSION

The Stirling engine is recognised for delivering high efficiency compared to steam engines, quiet operation, and the ease with which it could be used for almost any heat sources .Here solar power is utilised to operate the engine. The Stirling cycle engine has multi fuel capability so that it can operate with any alternate fuel source-liquid, gaseous or solid fuels with wide temperature range.

From the study, invention of the engine have made a good base line information for designing engine system, but a more insight is very much essential to design systems together for thermo-fluid-mechanical approach. It is seen that for the successful operation of such type of system, careful selection of drive mechanism and engine configuration is greatly essential. An additional development is needed to produce a practical engine by selection of suitable configuration; adopting a good working fluid and followed by development of good seal may make Stirling engine a real practical alternative for power generation. This feature of the engine has kept Stirling engine in focus for design and development for better system efficiency where there is large scope.

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