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Fabrication & Performance Test of a Low Temperature Differential Stirling Engine

Md Arafat Hossain, Shubhra Kanti Das, Md Sazzad Hossain
Department of Mechanical Engineering, Khulna University of Engineering and Technology (KUET), Khulna-9203, Bangladesh

Abstract— In recent years, understanding of the Stirling engine has enjoyed considerable growth. Research and development on the Stirling engine has steady progressed, and many new insights, inventions, and potential applications have many discovered and explored. One of the most exciting recent developments is the so called “Low temperature differential” Stirling engine. This new type of Stirling is capable of running on very small differences in temperature between the hot and cold sides, or better to say, between the warm and cool sides. Low temperature differential Stirling engine have been built that run on differentials ranging. This means that Stirling engines can now utilize low grade heat sources for their operation ranging from passive solar or geothermal energy to industrial process waste heat. Whether Low temperature differential Stirling engines can be put to practical use is an open question and still the subject of ongoing research and development work is being carried out worldwide at universities, government laboratories, and in private sector.

Index Terms— Displacer, Heat sink, Low Temperature differential, Regenerator, Temperature, The Stirling cycle, Stirling Engine,

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1 INTRODUCTION

A Stirling engine is a heat engine operating by cyclic compression and expansion of air or other gas as the working fluid. In the Stirling engine, all heat transfers to and from the working fluid take place through the engine wall. This contrasts with an IC engine where heat input is by combustion of a fuel within the thermodynamic body. Unlike a Rankine cycle engine, the Stirling engine encloses a fixed quantity of permanently gaseous fluid.

The Stirling engine is noted for its high efficiency compared to steam engines, quiet operation, and the ease with which it can use almost any heat source. This compatibility with alternative and renewable energy sources has become increasingly significant as the price of conventional fuels rises, and also in light of concerns such as peak oil and climate change.[1] This engine is currently exciting interest as the core component of micro combined heat and power (CHP) units, in which it is more efficient and safer than a comparable steam engine.[2]

2 OBJECTIVES

1. To study about and construct a Low Temperature Differential Stirling engine.
2. To observe the performance of this engine.

3 OVERVIEW OF STIRLING ENGINE

3.1The Stirling cycle

The idealized Stirling cycle consists of four thermodynamic processes acting on the working fluid:

1. **Isothermal Expansion**. The expansion-space and associated heat exchanger are maintained at a constant high temperature, and the gas undergoes near-isothermal expansion absorbing heat from the hot source.

2. **Constant-Volume (known as iso-volumetric or isochoric) heat-removal.** The gas is passed through the regenerator, where it cools transferring heat to the regenerator for use in the next cycle.

3. **Isothermal Compression.** The compression space and associated heat exchanger are maintained at a constant low temperature so the gas undergoes near-isothermal compression rejecting heat to the cold sink.

4. **Constant-Volume (known as iso-volumetric or isochoric) heat-addition.** The gas passes back through the regenerator where it recovers much of the heat transferred in 2 to 3, heating up on its way to the expansion space. [4]

Though theoretical thermal efficiency is higher than any heat engine, some real-world issues reduce the efficiency of actual engines, due to limits of convective heat transfer, and viscous flow (friction). [3]

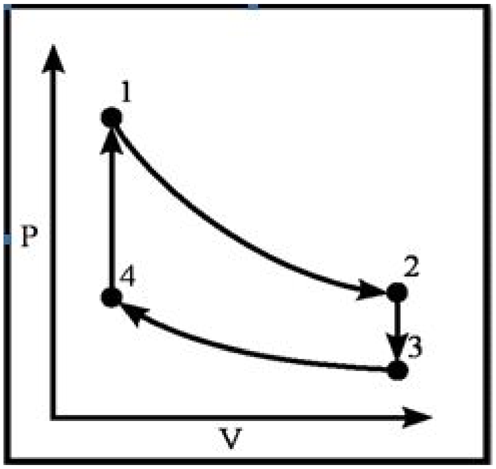


Figure 1: P-V diagram

3.2 The Real Stirling Process

For having the isothermal processes, it has to go infinitesimally slowly to always ensure equilibrium of temperature and it is difficult to realize the isochors processes while at the same time having an evenly running system. So in every Stirling engine built, the different steps are not separated strictly but overlap each-other.[5]

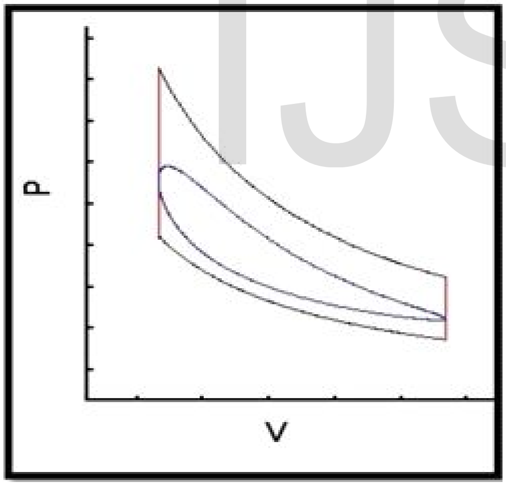


Figure 2: Ideal Stirling process P-V diagram

3.3 Operation

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, often with a regenerator between the heater and cooler. 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.

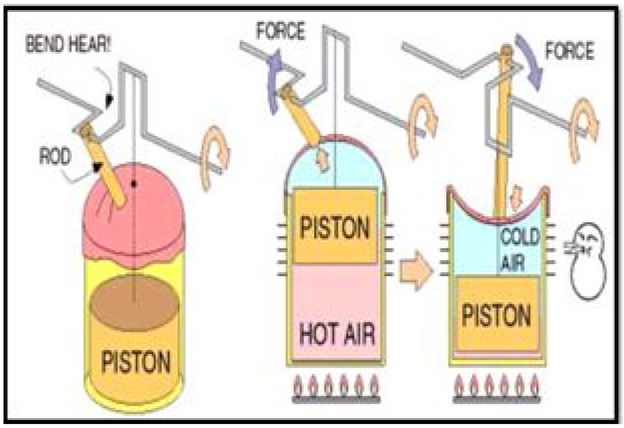


Figure 3: Stirling Engine's principle of operation

4 KEY COMPONENTS

As a consequence of closed cycle operation, the heat energy driving a Stirling engine must be transmitted from a heat source to the working fluid by heat exchangers and finally to a heat sink. A Stirling engine system has at least one heat source, one heat sink and up to five heat exchangers. Some types may combine or dispense with some of these

4.1 Heat source

The heat source may be combustion of a fuel or other suitable heat sources like concentrated solar energy, geothermal energy, nuclear energy, waste heat, or even biological. Solar powered Stirling engines are increasingly popular as they offer an environmentally sound option for producing power while some designs are economically attractive in development projects.[6]

4.2 Heater / hot side heat exchanger

Designing Stirling engine heat exchangers is a balance between high heat transfer with low viscous pumping losses and low dead space (unswept internal volume). With engines operating at high powers and pressures, the heat exchangers on the hot side must be made of alloys retaining considerable strength at temperature that also will not corrode or creep.

4.3 Regenerator

In a Stirling engine, the regenerator is an internal heat exchanger and temporary heat store placed between the hot and cold spaces such that the working fluid passes through it first in one direction then the other. Its function is to retain within the system that heat which would otherwise be exchanged with the environment at temperatures intermediate to the maximum and minimum cycle temperatures, thus enabling the thermal efficiency of the cycle to approach the limiting Carnot efficiency defined by those maxima and minima.[7]

A typical design is a stack of fine metal wire meshes, with low porosity to reduce dead space, and with the wire axes perpendicular to the gas flow to reduce conduction in that direction and to maximize convective heat transfer.

4.4 Cooler / cold side heat exchanger

In small, low power engines this may simply consist of the walls of the cold space(s), but where larger powers are required a cooler using a liquid like water is needed in order to transfer sufficient heat.

4.5 Heat sink

The heat sink is typically the environment at ambient temperature. In the case of medium to high power engines, a radiator is required to transfer the heat from the engine to the ambient air. Marine engines can use the ambient water.

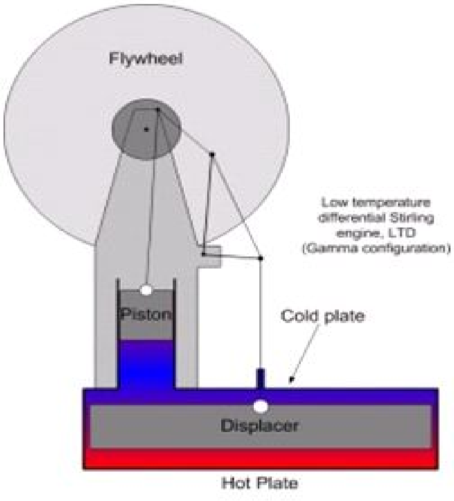
4.6 Displacer

The displacer is a special-purpose piston, used in Beta and Gamma type Stirling engines, to move the working gas back and forth between the hot and cold heat exchangers. Depending on the type of engine design, the displacer may or may not be sealed to the cylinder.

Construction of a Low Temperature Differential (LTD) Stirling Engine, List Components

- Piston
- Displacer
- Cylinder
- Connecting rods and linkages
- Flywheel
- Hot side plate or heat exchanger
- Cold side plate or heat exchanger

4.8



Shape of an LTD Stirling Engine

Figure 4: Model of Low Temperature Differential Stirling Engine (Right Side View)

LTD engines have a relatively large volume of working fluid and displacer to compensate for the small amounts of energy available when running on such small heat differences. Stirling engines use a working fluid (gas) in many cases typical atmospheric air. The air must be sufficiently heated to expand and push the piston outward the appropriate distance for the engine to operate. In the case of a low temperature differential Stirling a relatively small amount of gas is heated.

Figure 5: Model of Low Temperature DifferentialStirling Engine (Three Dimensional View)

An LTD Stirling engine aims to do the opposite. To offset the small heat difference it heats a relatively large amount of gas. This leads to LTD Stirling engine designs that have a relatively large surface area for the heating and cooling plates. These plates allow a larger volume of gas to be affected. It is also necessary to have a displacer that has nearly the same surface area as the heating and cooling plates. The displacer is almost always light weight and has high insulative properties. A correctly shaped displacer is needed in order to move a large volume of gas. Also, a light weight displacer with a large surface and a short stroke are necessary and typical for LTD engines.

4.9 Prototype

Figure 6: LTD Stirling Engine (prototype-front view)

Figure 7: LTD Stirling Engine (prototype-side view)

4.10 The Performance of Low Temperature Differential Stirling Engine

The thermal efficiency of an engine is the work that it delivers to the piston in a cycle divided by the heat that it takes in. It is the measure of how good the engine is at converting heat into raw mechanical energy.

Thermal Efficiency, $\eta = (T_H - T_C / T_H)$

4.11 Data Analysis of Stirling Engine

Table 1
No cold water on upper surface

Upper Surface Temperature, T_C (K)	Lower Surface Temperature, T_H (K)	Temperature Difference	RPM of Flywheel	Thermal Efficiency, η (%)
293	293	0	0	0
303	318	15	60	4.72
313	343	30	109	8.75
323	343	20	80	5.83
333	343	10	43	2.92

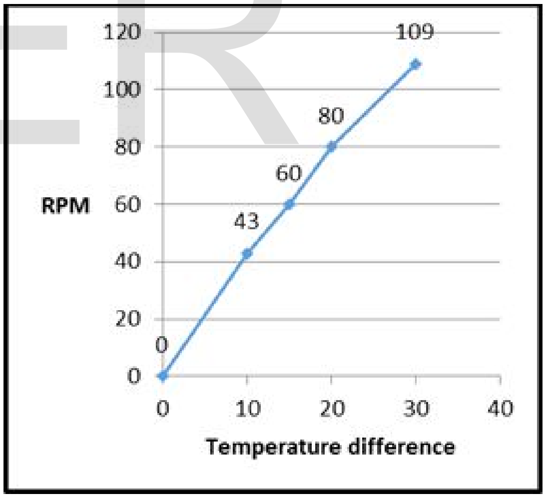


Figure 8: Temperature vs. RPM graph.

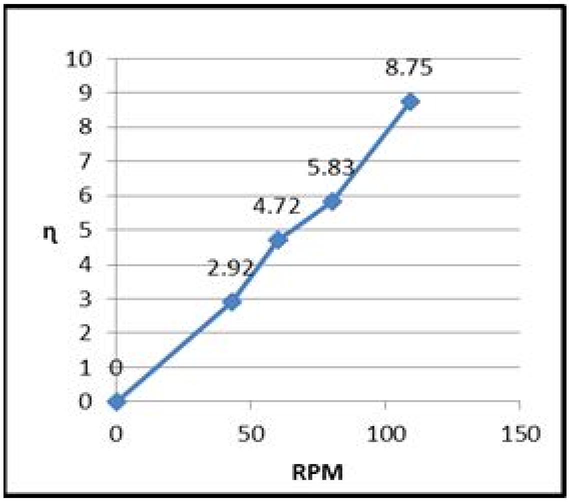


Figure 9: RPM Vs. η Graph

Table 2
After putting cold water on upper surface

Upper Surface Temperature, T_C (K)	Lower Surface Temperature, T_H (K)	Temperature Difference	RPM of Flywheel	Thermal Efficiency, η (%)
313	343	30	60	8.75
318	343	25	63	7.30
323	343	20	55	5.83
333	343	10	45	2.92
335	343	8	43	2.33

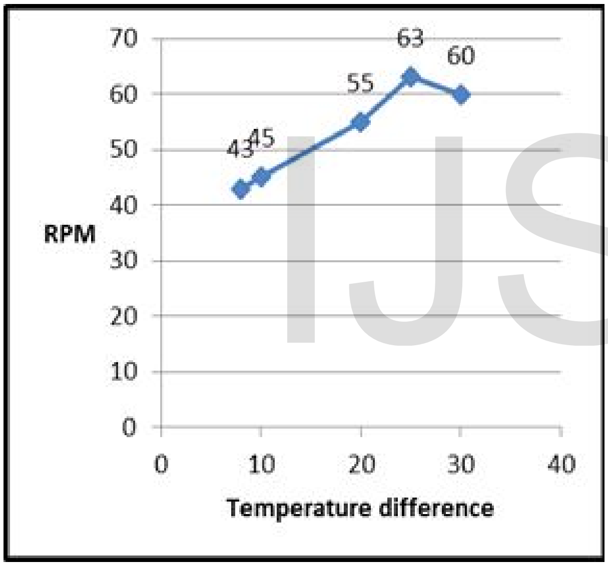


Figure 10: Temperature vs. RPM graph

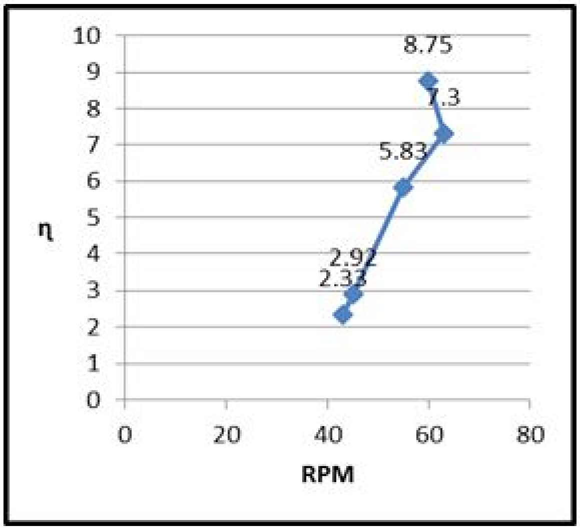


Figure 11: RPM Vs. η Graph

5 HOW TO OVERCOME COMMON PROBLEMS

After examining thoroughly it was notified that in order to run successfully, the volume of the power piston should increase so that its displaced volume would increase. The flywheel should be chosen very carefully. Proper stroke adjustment is also necessary. This model requires decreasing the height of the displacer cylinder chamber. Finally the proper sealing must be insured. Slow speed operation is an intrinsic characteristic of LTD engines. The displacer causes this to happen by moving the air back and forth between the hot and the cold sections of the engine. When cold air enters the hot section, it picks up heat from the hot engine surfaces and so rises in temperature. When the warm air is later moved back into the cooler section, it loses thermal energy to the cooler engine surfaces and drops in temperature. It is this cyclic "change in the temperature of the working air that causes its pressure to change and drives the piston to run the whole machine and do useful work".

6 ADVANTAGES AND DISADVANTAGES OF STIRLING ENGINE

6.1 Advantages

- The heat is external and the burning of a fuel-air mixture is accurately controlled.
- A continuous combustion process is used to supply heat, so emission of unburned fuel can be greatly reduced.
- Most types of Stirling engines have the bearing and seals on the cool side; consequently, they require less lubricant and last significantly longer between overhauls than other reciprocating engine types.
- The engine as a whole is much less complex than other reciprocating engine types. No valves needed. Fuel and intake systems are very simple.
- They operate at relatively low pressure and thus are much safer than typical steam engines.
- Low operating pressure allows the usage of less robust cylinders.
- They can be built to run very quietly and without air, for use in submarines.
- They hold promise as aircraft engines. They are quieter, less polluting, gain efficiency with altitude are more reliable due to fewer parts and the absence of an

ignition system, produce much less vibration (air-frames last longer) and safer, less explosive fuels may be used. [8]
- Stirling engines, especially the type that run on small temperature differentials, are quite large for power that they produce, due to the heat exchangers.
- A "pure" Stirling engine cannot start instantly; it literally needs to "warm up". This is true of all external combustion engines, but the warm up time may be shorter for Stirling.
- Power output of a Stirling is constant and hard to change rapidly from one level to another. [8]

6.2 Disadvantages

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- A "pure" Stirling engine cannot start instantly; it literally needs to "warm up". This is true of all external combustion engines, but the warm up time may be shorter for Stirling.
- Power output of a Stirling is constant and hard to change rapidly from one level to another. [8]

7 CONCLUSION

Stirling cycle engines are very efficient for a given temperature difference between the heat source and the heat sink. Stirlings avoid fluid containment problems, as they can run with air as the working fluid, and will have less maintenance issues. Also, they can be constructed in a way that they produce no emissions. That means, in combination with solar or geothermal heat, they can be used as a renewable energy source to produce electricity.

Thus, the Stirling engine has strong economic practicality. The original cost is quite lower than for any other engines. Even a few calories can drive it and keep it running. In addition, the auxiliary costs are low, because the Stirling engine costs little on environment protection. The fuels it uses can remain cleaned, so it costs little to handle the pollution. The Stirling engine is consistent with the requirements of sustainable development. It is the main development way in the future, so the Stirling engine does not only meet the economic needs at present time, but also in the future.

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