A Review of Design of Stirling Engines

Assistant Professor **Sunny NARAYAN**[1]

[1] Indus International University, Himachal Pradesh, India, rarekv@gmail.com

Abstract: *This work provides a review of n solar-powered Stirling engines devices. Previous works have focussed on the solar powered as well as low temperature differential engines. The aim of this work is to review working fluids for operation of this engine. Air was found to be a good alternative as a working medium for gamma type engines.*

Keywords: *Stirling Engines*

1. Introduction

In a Stirling engine the fluid is contained in a confined space, hence there are no problems of contamination. In order to reduce the heat losses, the mass flow rate must be low which can be maintained by low viscosity fluid or high working pressures. These engines are 30 to 40% efficient in a temperature range of 923–1073 K.[1].

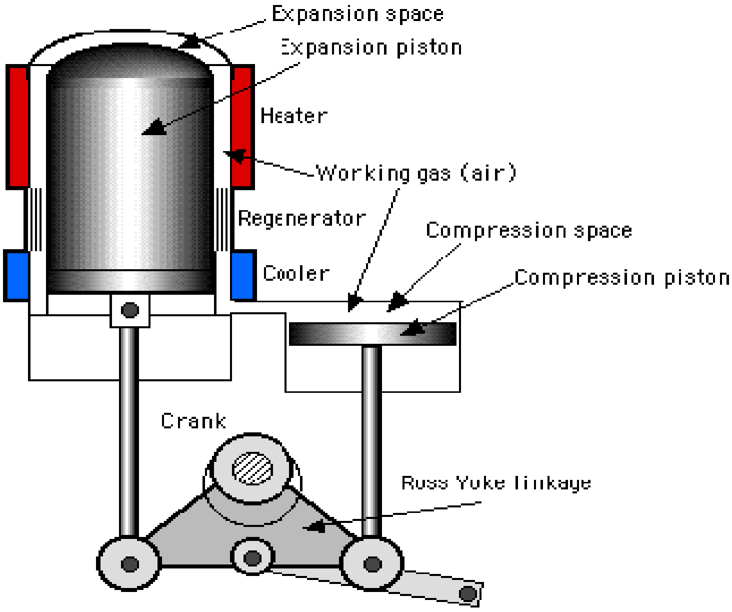

Fig. 1. Stirling engine [2]

A Stirling engine consists of following components:

1. **Heat source**-as fuel does not come in direct contact with the working fluid, Stirling engines can work on fluids which may damage parts of a conventional engine.
2. **Regenerator**-the function of regenerator is to use the waste heat from being lost to environment by storing it temporarily, thus helping to achieve high efficiencies close to an ideal Carnot cycle. A simple configuration consists of fine mesh of metallic wires. In an ideal Stirling cycle, the connecting space between hot and cold ends acts as regenerator.
3. **Heat sink**-typically the ambient environment acts as an ideal heat sink; otherwise the cold side can be maintained by iced water or cold fluids like liquid nitrogen.
4. **Displacer piston**-it causes the displacement of working gas between hot and cold regions so that expansion and contraction occurs alternatively for operation of engine.
5. **Power piston**- transmits the pressure to crankshaft.

In a Stirling engine, hot air expands when heated and contracts when cooled. This principle of operation was most properly understood by Irish scientist Robert Boyle from his results on experiments on air trapped in a J shaped glass tube. Boyle stated that pressure of a gas is inversely proportional to its volume and product of pressure and volume occupied is a constant depending on temperature of gas.

Hence PV=NRT

Various assumptions which are made in this cycle are [3]:

1) Working fluid is an ideal gas.

2) Conduction and flow resistance is negligible.

3) Frictional losses are neglected.

4) Isothermal expansion and contraction.

This cycle can be described by following stages: [3]

1) Phase C-D: Isothermal expansion-the working fluid undergoes an isothermal expansion absorbing the heat from source. The power piston moves out, hence increasing the volume and reducing the pressure. The work done in expansion of gas is given by:

$$We = RTln\left[\frac{V_D}{V_C}\right] = \int pdv = nRTc\ ln\left[\frac{V_D}{V_C}\right] \quad (1)$$

2) Phase D-A: Power piston now reaches the outermost position and stays there so that volume is constant. The working fluid is passed through the regenerator where it gives up heat for use in next cycle. Hence its temperature and pressure falls. No work is done during this phase.

3) Phase A-B: The power piston stats moving inwards, reducing its volume and increasing its pressure the working fluid gives up heat to cold sink. The work done in compressing the gas is given by:

$$Wc = RTln\left[\frac{V_B}{V_A}\right] = \int pdv = nRTh\ ln\left[\frac{V_B}{V_A}\right] \quad (2)$$

4) Phase 2-3: The power piston is at its most inwards point and stays there to keep volume constant. Working fluid passes again through the regenerator, recovering the heat lost in 2nd phase, hence its pressure and temperature goes up.

$$Wnet = We - Wc$$

$$= nR[Th - Tc]\left[\frac{Vmax}{Vmin}\right] \quad (3)$$

But

$$V_B = V_C\ \&\ V_A = V_D$$

$$efficiency\ of\ engine = \eta = \frac{Wnet}{Qe} = \frac{nR(Th - Tc)\ln\left[\frac{Vmax}{Vmin}\right]}{nR\ Th\ \ln\left[\frac{Vmax}{Vmin}\right]}$$

$$\eta = \frac{Th - Tc}{Th} \quad (4)$$

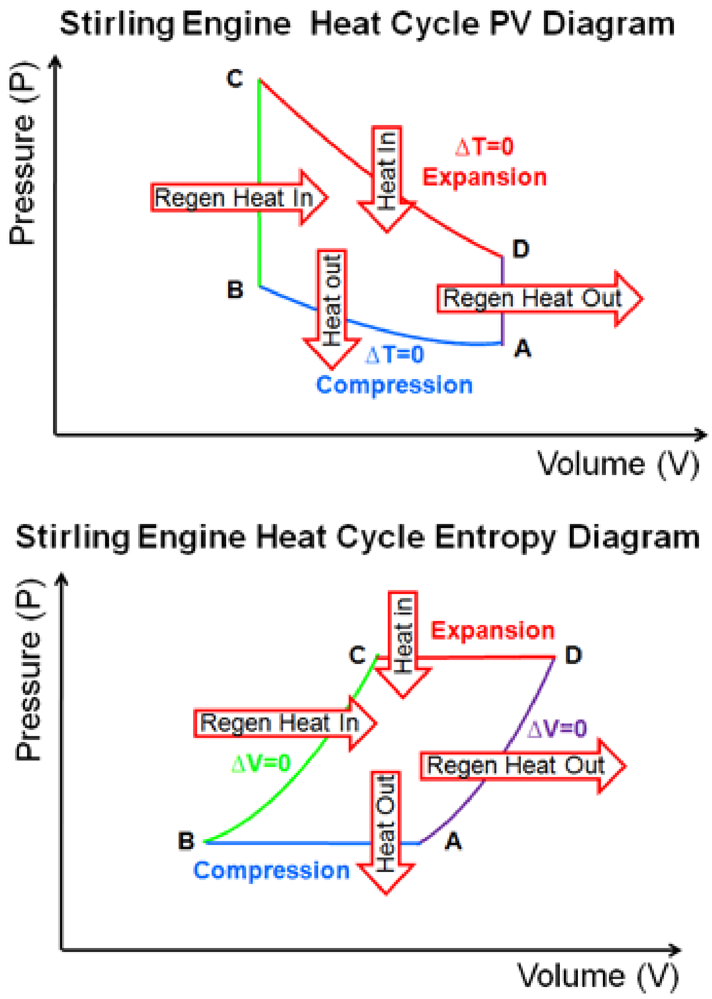

Fig. 2. P-V & T-S plot of a Stirling cycle [4]

In Stirling cycle, two Isochoric processes replace the two Iso-entropic processes s in an ideal Carnot cycle. Hence more work is available than a Carnot cycle as net area under P-V curve is more. Thus there is no need for high pressures or swept volumes. This can be seen in the figures presented below.

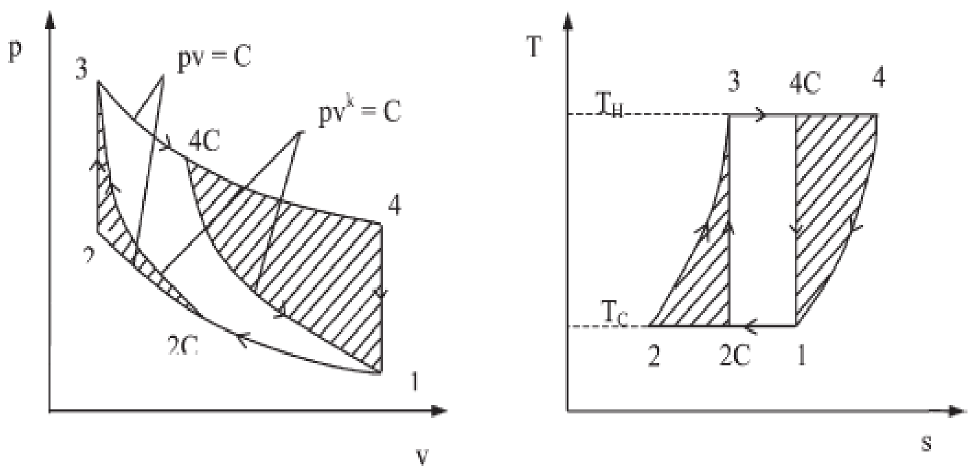

Fig. 3. Comparison of Stirling cycle and Carnot cycle [5]

2. Types of engines [6]

Stirling engines can be further classified as alpha, beta or gamma type. Alpha version consists of two power pistons in series with heat sink, heat source and regenerator.

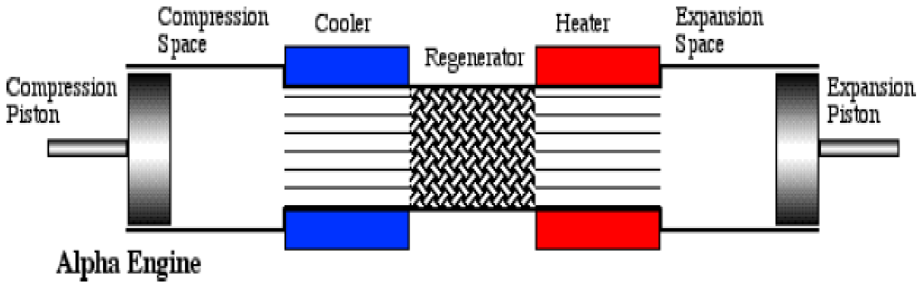

Fig. 4. An Alpha Stirling engine configuration

2.1 Working of an Alpha Stirling engine [6]

This engine consists of following stages:

1) Expansion-working gas is present in hot side and gains heat expanding, hence pulling both pistons inwards.

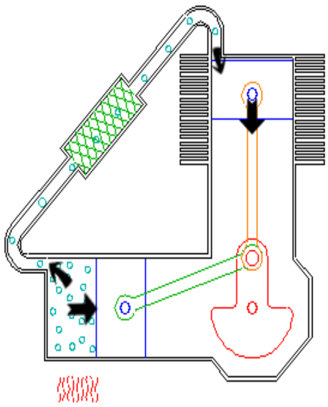

Fig. 5. Working stages of an Alpha Stirling Engine

2) Transfer Motion of crank shaft transfers most of the gas from hot side towards the cold side.

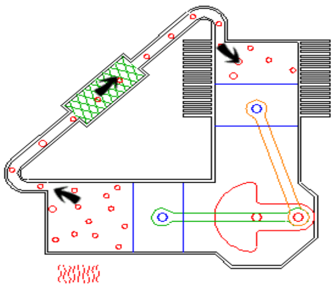

Fig. 6. Working stages of an Alpha Stirling Engine

3) Contraction-Working gas is transferred towards cold side, cools and contacts pushing both pistons outwards.

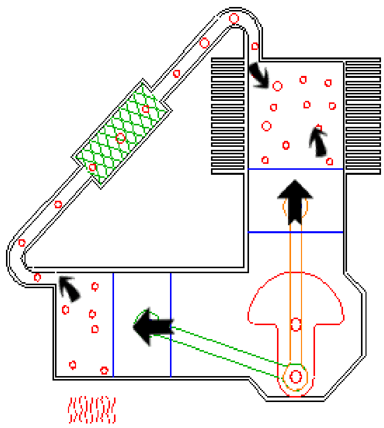

Fig. 7. Working stages of a Alpha Stirling Engine

4) Transfer-Motion of crank shaft through 90° causes transfer of gas again to hot side so that cycle is repeated again.

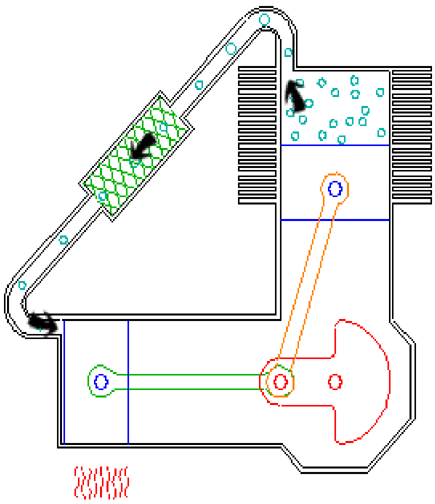

Fig. 8. Working stages of a Alpha Stirling Engine [16]

2.2 Working of a Beta Stirling engine [6]

Beta type engine and gamma type engine have a single power piston, whereas alpha type engine have two power pistons. Beta type Stirling engine has both power and displacer pistons on the same axis whereas in gamma configuration, both pistons are separate. Gamma engines are best suited for studies whereas Beta ones are difficult to fabricate.

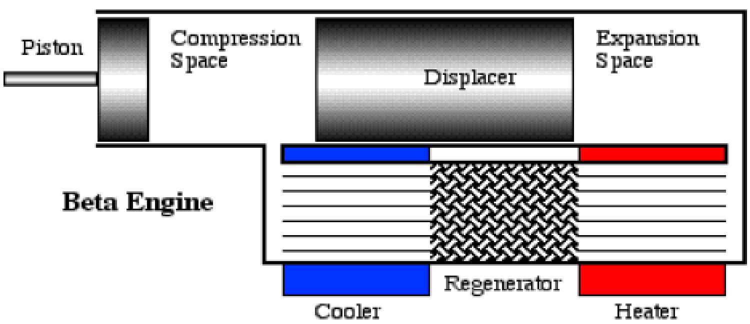

Fig. 9. A Beta Stirling engine

Working of a beta engine can be understood in following cycles:
1) Expansion-most of the gas is at the hot end, which gains heat and expands.

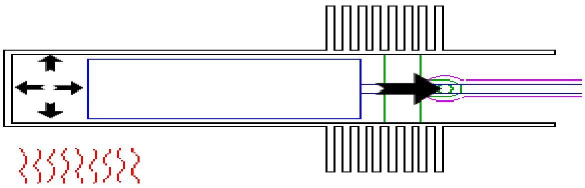

Fig. 10. Working stages of a Beta Stirling Engine

2) Transfer-motion of fly wheel causes gas to move towards cold end passing over the displacer.

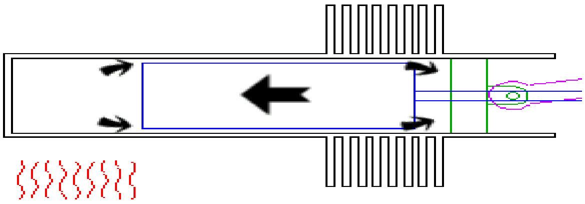

Fig. 11. Working stages of a Beta Stirling Engine

3) Contraction-most of the gas is in cold end where it cools and contracts drawing piston inwards.

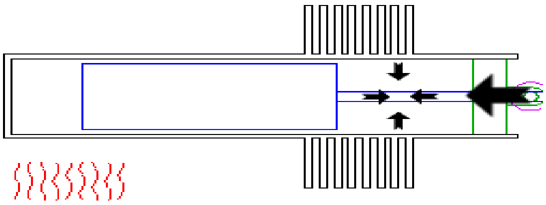

Fig. 12. Working stages of a Beta Stirling Engine

4) Transfer-motion of flywheel causes displacer to move out, transferring gas again to hot end.

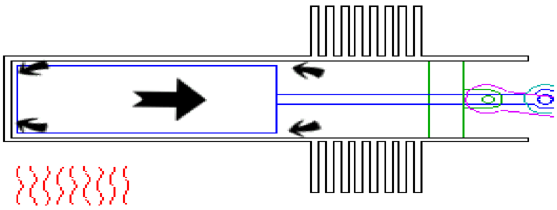

Fig. 13. Working stages of a Beta Stirling Engine

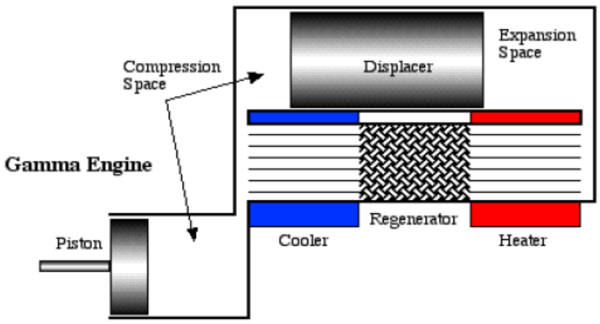

Fig. 14. A Gamma Stirling engine

3. Working gas

It is a gas on which engine operates. There are several gases that can be used to run a Stirling engine. Lighter gases having atomic mass lesser than that of air have higher specific heat and gas constant and lower viscosity resulting in lesser viscous losses and higher heat storing capacity [7].This can be seen in the following graph which was obtained by simulation by Philip Brothers.

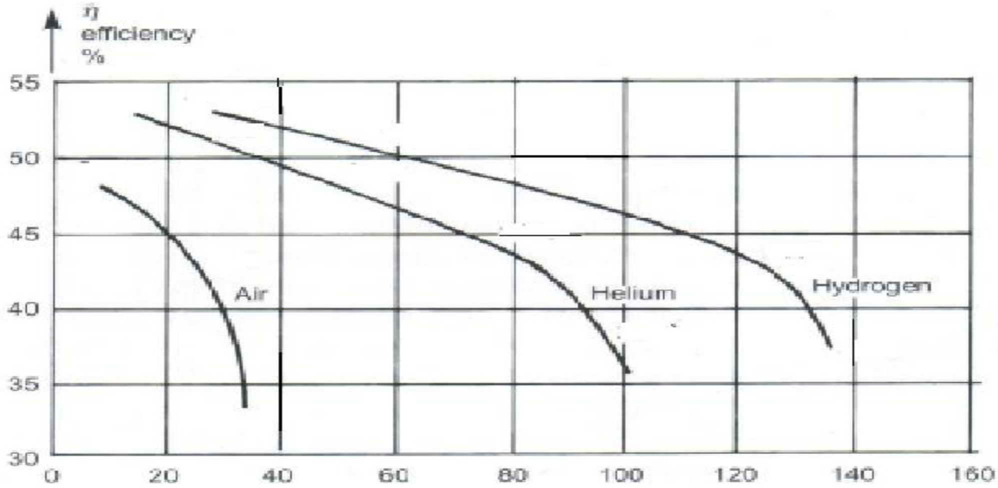

Fig. 15. Stirling engine efficiency V/S power output for various gas [8]

4. Pros and cons of Stirling engine

Stirling engine has some merits as well as demerits which are discussed below

1) Merits
A) Stirling engines can be run on wide variety of fuels including solar energy without need for fuel to come in contact with operating gas hence avoiding containment. Hence even if solar energy is unavailable, alternative fuels can be used for operations. Thus these devices are not susceptible to fuel shortage.
B) Low and noise less operations are possible. Hence suitable for submarines.
C)Lower maintenance is needed and combustion of fuel occurs outside the engine.
D) Can be used as a CHP unit.
E) No danger of explosion as in steam engines.

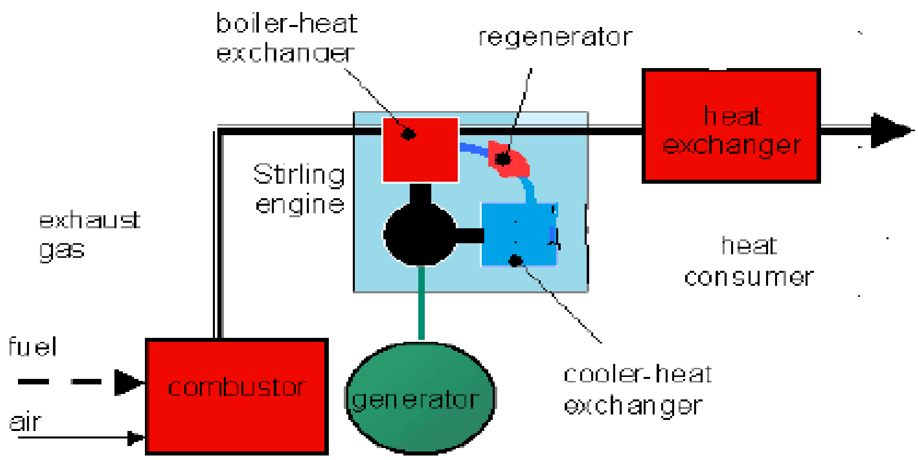

Fig. 16. A CHP Stirling engine

2) Demerits
A) Commercial feasibility not possible on large scale manufacturing.
B) Takes time to start from the cold.

5. Low temperature difference Stirling engine

These engines can run at a typically low temperature difference of less than 100°C between hot and cold end .with high temperature difference between hot and cold end, it is necessary to maintain long separation between hot and cold ends where as area of heating and cooling is less important. In year 1980 Sneft and Kolin developed of simple versions of such engines where a cup of hot tea could be used as a heat source. The upcoming figures show clear distinguish between the LTD &HTD engines.

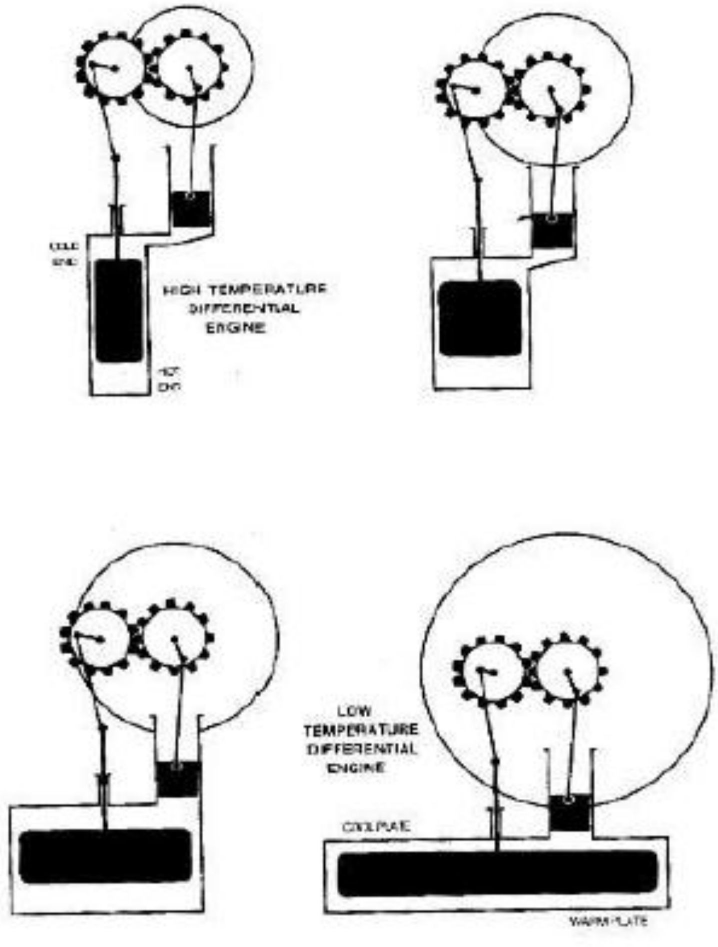

Fig. 17. Comparison of LTD and HTD engines [9]

6. Conclusions

This work reviews research works done in field of technology of Stirling engines, solar-powered Stirling engines, and LTD Stirling engines. The keys ways to improve the efficiency of the engine is to device new materials for good heat transfer to the working fluid. Lower viscosity working fluid pumped at higher pressure is ideal condition for good heat transfer. The efficiency of Stirling engine may be low, but it has high reliability and low setup costs.
For use in rural areas reflector can be used to focus the solar energy on a displacer hot-end surface for heat transfer by conduction to the air inside the displacer cylinder. The air expands and moves the power piston which in turn can be useful for mechanical power output.

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