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A REVIEW ON STIRLING ENGINES

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ABSTRACT

An Internal Combustion Engine (IC) is one of the most predominantly used devices for generating power and acting as prime movers. Most of the Internal Combustion Engines available in the present world run either on the Otto Cycle or on the Diesel Cycle. In these types of engines, a new mass of gas (working fluid) enters the system in every cycle. Unlike these engines, a Stirling Engine has a permanently gaseous working fluid, which always remains in the system.

The Stirling Engine is a closed cycle type regenerative engine. These engines are broadly classified as Alpha type, Beta type and Gamma type. The engine consists of one or two cylinders depending upon the type of the engine and both the cylinders are connected to each other by a passage.

The Stirling Engine is based on the Stirling Cycle and works on the phenomenon that gases expand when heated and get compressed when cooled. One of the cylinders is heated while the other one is kept at a relatively lower temperature. The working fluid (generally air) inside the cylinder undergoes cyclic compression and expansion due the temperature difference. This process results in displacement of the pistons in their respective cylinders, thereby providing power at the output.

This paper throws light on the working, advantages, limitations and applications of the Stirling Engine.

Keywords: Regenerator, Stirling Cycle, Stirling Engine

I. INTRODUCTION

A Stirling Engine is a closed cycle type regenerative engine that has a permanently gaseous working fluid. A Scottish minister named Robert Stirling invented engine and hence it is named after him. His invention of the first practical closed cycle air engine dates back to 1816.

The operation of this engine is based on the Stirling Cycle and involves cyclic compression and expansion of air (working fluid) by a temperature difference in the engine, resulting in conversion of heat energy to mechanical energy.

The Stirling Cycle is a thermodynamic cycle which is an altered form of the Carnot cycle wherein the two isentropic processes of the Carnot cycle are replaced by two isochoric (constant volume) regeneration processes. Here the term regeneration refers to the use of a regenerator which is basically a heat exchanger and it improves the thermal efficiency of the engine [1].

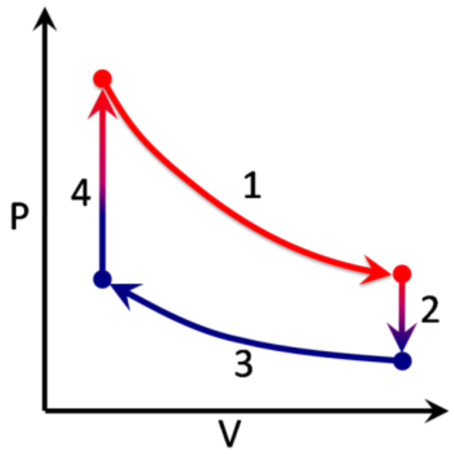

Fig. 1 Stirling Cycle on a p-V plane

The processes involved in the figure above are as follows:

1) 1-2 Isothermal expansion
2) 2-3 Isochoric heat removal
3) 3-4 Isothermal compression
4) 4-1 Isochoric heat addition

II. HISTORY

Robert Stirling invented and patented the Stirling Engine, which was then known as the Stirling's Air Engine, in the year 1816. Stirling's Engine was first put to practical use in pumping water in a quarry, a couple of years after its invention, in the year 1818 [2].

The most distinctive feature of Stirling's patent was the economizer, which is now referred to as regenerator. It is a heat exchanger which improves the thermal efficiency of the engine.

III. KEY COMPONENTS

Gases expand when heated and get compressed when cooled. This is the basic phenomenon on which the Stirling Engine works. This cyclic expansion and compression of the gas transforms the heat energy into mechanical work. For this process, the following components are essential in the Stirling Engine.

1) Heat Source – Heat needs to be provided for the expansion of the gas. This heat is obtained form an external heat source. As the heat source is external, it provides a wide range for selection of the heat source along with the flexibility to use different and non conventional heat sources. There are some fuels like landfill gas which can damage the internal components of a conventional IC engine. But, as the heat source is external in Stirling Engines, these types of fuels can be used for the heating purpose.

Some other type of heat sources include non conventional sources like geothermal energy, solar energy, nuclear energy, waste heat, etc.

2) Regenerator – This is the most distinctive component of the Stirling Engine that separates it from the other hot air engines. A regenerator, also known as economizer, is a type of internal heat exchanger and a temporary heat storage place between the hot and cold portions.

The main function of the regenerator is to transfer heat from one direction to the other. This retains the heat energy which would otherwise get lost to the surroundings. This takes the thermal efficiency of the Stirling Engine near to the Carnot efficiency [3].

The construction of a regenerator can be as simple as having metal meshes that offer low flow resistance, high heat capacity, low conductivity and maximum surface area.

3) Displacer – In the Beta and Gamma type configurations of the Stirling Engine, a special purpose piston is used to displace the working fluid back and forth in the hot and cold regions of the engine. Heat Sink – The heat sink in these engines is same as that of in the conventional IC engines i.e. the ambient atmosphere. Sometimes in heavy duty application engines, a radiator is required to transfer heat from the engine to the ambient. In marine applications of the Stirling Engine, the ambient environment is the water.

IV. CONFIGURATIONS

The Stirling Engine is broadly classified as the Alpha type, Beta type and Gamma type.

1) Alpha Configuration – The Alpha configuration has two cylinders and two power pistons. One is in the hot cylinder and the other in the cold cylinder. The working fluid passes through the hot and cold sections displacing the respective pistons.

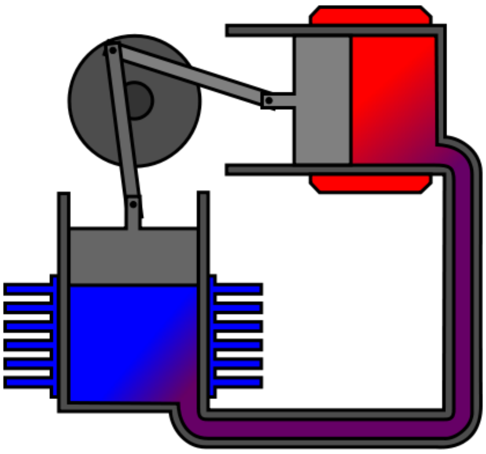

Fig. 1 Alpha type

The Alpha configuration is typically a V type construction and the two pistons are joined at the same point of the crankshaft.

2) Beta Configuration – The Beta configuration consists of only cylinder and has one power piston along with the special purpose displacer piston. The cylinder has a hot end and a cold end. The displacer piston is responsible for driving the gas form the two temperature ends [4].

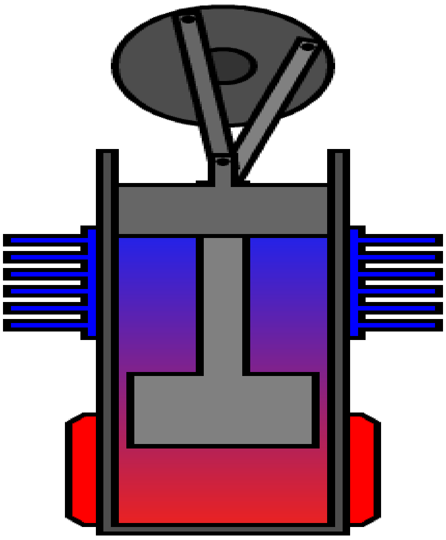

Fig. 2 Beta type

The phase difference between the power piston and the displacer piston is achieved by using a rhombic drive. They can also be joined at 90 degree out of phase on the crankshaft.

3) Gamma Configuration – The Gamma configuration has two cylinders with the power piston in one cylinder and the displacer piston in the other. In this type of configuration, the hot and cold ends are in the cylinder of the displacer piston.

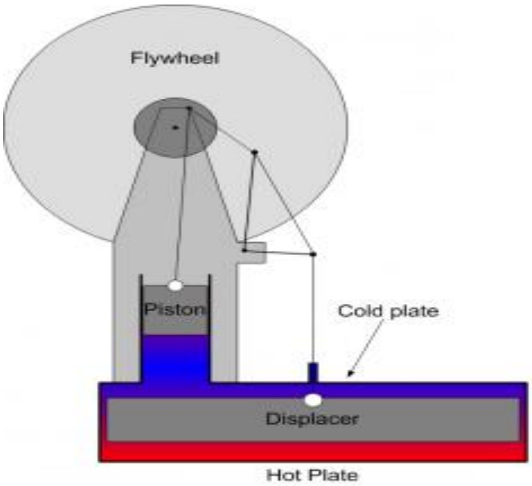

Fig. 3 Gamma type

The two cylinders are joined in such a way that the pressure in both the cylinders remains the same. The two pistons are typically parallel to each other and are joined 90 degree out of phase on the crankshaft.

V. WORKING

The operation of the Stirling Engine involves the same operations as that of a conventional IC engine i.e. heating, expansion, cooling and compression. But, unlike the conventional IC engines, the working fluid of the Stirling Engine is a permanently gaseous type. Also, the engine is a closed cycle type which means that no gas comes in or goes out of the engine.

The mechanical work output from the engine is achieved by providing thermal energy input. One of the cylinders is heated while the other one is kept at a relatively lower temperature (generally ambient). The gas in the hot section heats up and as it is enclosed in the cylinder by the piston, it expands and displaces the piston. Also, the hot cylinder is at its maximum volume whereas the cold cylinder is at its minimum value. Therefore, the gas expands into the cold cylinder where the gas is cooled. This transfers the volume of the gas to the cold cylinder. At this stage, the system is at its maximum value.

Due to the momentum stored in the flywheel as a result of the expansion of the gas, the piston in the hot cylinder begins an upstroke pushing the gas into the cold cylinder and thus reducing the volume of the system. Almost all the working fluid gets transferred to the cold cylinder during this process where the gas gets cooled. Due to the cooling of the gas, it contracts thereby putting the system to its minimum volume. Again, due to the momentum of the flywheel, the movement of the piston initiates and the gas begins to get transferred to the hot cylinder where it is heated again.

This process continues in a cyclic manner, thereby converting the thermal energy to mechanical work output. Here, as like the conventional IC engines, the environmental parameters affect the performance of the engine. More the temperature difference between the hot and cold sides more is the efficiency of the engine.

During this cyclic process, the gas travels in the cylinders through a passage. This passage has a key element called the regenerator. The regenerator is temporary heat storage and a heat exchanger which transfers heat from one direction to the other. It also retains the heat in the system and does not allow it to get dissipated into the atmosphere. This increases the overall thermal efficiency of the engine.

The key point here is that if the hot and cold cylinders in the engine are interchanged, the engine crank will start rotating in the opposite direction.

VI. ADVANTAGES

- High thermal efficiency, close to limiting Carnot efficiency.
- Wide option available for heat source, both conventional and non conventional.
- Lesser emissions.
- Noiseless operation.
- Light weight.
- Compact.

VII. LIMITATIONS

- The high temperature side of the engine must be resistant to corrosion and must have low creep. Materials for such applications are costly thereby increasing the cost of the engine.
- Best results are achieved in colder atmospheres.
- For higher thermal efficiency, the colder side must be kept at quite low temperatures. For achieving this, the size of the radiators increases. Thus, the packaging of the components becomes difficult.
- A Stirling Engine does not start instantly. It needs a small warm-up.

VIII. APPLICATIONS

The applications of Stirling engines range from heating and cooling to underwater power systems. A Stirling Engine can also function in reverse as a heat pump for heating or cooling. The other uses include combined heat and power, solar power generation, Stirling cryocoolers, heat pump, marine engines, low temperature difference engines and low power aviation engines [5].

IX. CONCLUSION

From the data above, it can be concluded that the Stirling Engines have a tremendous potential to replace the conventional power generating devices but, there are numerous limitations on it. The Stirling Engines have a wide scope for improvement and it can prove to be a promising power source after further improvements.

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