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STIRLING ENGINE

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Abstract: - In the process of transforming thermal energy into mechanical work, among the known thermal machines, the Stirling engine is the one that can achieve the highest yield. This type of engine can operate on the basis of a heat source irrespective of its quality, whether it is solar, chemical, nuclear, biological, etc. The performance of Stirling engines meets the demands of the efficient use of energy and environmental security and therefore they are the subject of much current interest. Hence, the development and investigation of Stirling engine have come to the attention of many scientific institutes and commercial companies. The Stirling engine is both practically and theoretically a significant device, its practical virtue is simple, reliable and safe which was recognized for a full century following its invention. The objective of this paper is to provide basic information about Stirling engine.

I. INTRODUCTION

Have you ever wondered, why do we need an explosion inside an engine cylinder? The answer is that we require to cause a movement of piston in order to get output from the crankshaft, but let's just think about if it is just about the piston movement so why do we depend on explosion? We can cause the movement with various other means which are much more efficient and easier than combustion, now the question is how it is done? And here lies the answer Stirling Engine.

A Stirling engine is the type of engine in which unlike the internal combustion engine the heat energy source is external that can be achieved by various means like it can be achieved by burning fuel or it can be done by any electric means depending on the efficiency required. It operates by cyclic compression and expansion of working fluid at different temperature levels such that there is a net conversion of heat energy to mechanical work. This contrasts with an internal combustion engine where heat input is by combustion of a fuel within the body of the working fluid. As is the case with other heat engines, the general cycle consists of compressing cool gas, heating the gas, expanding the hot gas, and finally cooling the gas before repeating the cycle. The Stirling engine is exceptional for of its high efficiency compared to steam engines, quiet in operation and the ease with which it can use almost any heat source.

II. HISTORY

The Stirling engine was invented by Robert Stirling on September 27, 1816. The device was in the form of an inverted heat engine, and incorporated the characteristic phase shift between the displacer and piston that we see in all Stirling Engines today. It followed earlier attempts at making an air engine but was probably the first put to practical use when, in 1818, an engine built by Stirling was employed pumping water in a quarry.

The engine also featured the cyclic heating and cooling of the internal gas by means of an external heat source, but the device was not yet known as a Stirling Engine. That name was coined nearly one hundred years later by Dutch engineer Rolf Meijer to describe all types of closed cycle regenerative gas engines. Though it has been disputed, it is widely supposed that as well as saving fuel, the inventors were motivated to create a safer alternative to the steam engines of the time whose boilers frequently exploded, causing many injuries and fatalities.

Stirling patented a second hot air engine, together with his brother James, in 1827. They inverted the design so that the hot ends of the displacers were underneath the machinery and they added a compressed air pump so the air within could be increased in pressure to around 20 standard atmospheres (2,000 kPa).

The two Stirling brothers were followed shortly after (1828) by Parkinson & Crossley and Arnott in 1829.
These precursors, to whom Ericsson should be added, have brought to the world the hot air engine technology and its enormous advantages over the steam engine. Each of them came with his own specific technology, and although the Stirling engine and the Parkinson & Crossley engines were quite similar, Robert Stirling distinguished himself by inventing the regenerator.

Parkinson and Crosley introduced the principle of using air of greater density than that of the atmosphere, and so obtained an engine of greater power in the same compass. James Stirling followed this same idea when he built the famous Dundee engine.

But subsequent to the failure of the Dundee foundry engine there is no record of the Stirling brothers having any further involvement with air engine development and the Stirling engine never again competed with steam as an industrial scale power source. However, from about 1860, smaller engines of the Stirling/hot air type were produced in substantial numbers finding applications wherever a reliable source of low to medium power was required, such as raising water or providing air for church organs. Several types remained in production beyond the end of the century, but

apart from a few minor mechanical improvements the design of the Stirling engine in general stagnated during this period.
During the early part of the twentieth century the role of the Stirling engine as a "domestic motor" was gradually taken over by electric motors and small internal combustion engines. By the late 1930s, it was largely forgotten, only produced for toys and a few small ventilating fans. In 1996, the Swedish navy commissioned three Gotland class submarines. On the surface, these boats are propelled by marine diesel engines. However, when submerged, they use a Stirling-driven generator to recharge batteries or provide electrical power for propulsion. A supply of liquid oxygen is carried to support burning of diesel fuel to power the engine. Stirling engines are also fitted to the Swedish Södermanland-class submarines. Swedish shipbuilder Kockums has also supplied Stirling engines to Japan, which intends to fit them to all its new submarines. In a submarine application, the Stirling engine offers the advantage of being exceptionally quiet when running.

Stirling engines are at the heart of Concentrated Solar Power technology, known as CSP Dish-Stirling. Several companies such as Cleanergy, Ripasso Energy and United Sun Systems International are involved in this technology.

III. COMPONENTS

As we know it is a closed cycle operation so as a consequences heat driving in a Stirling engine must be transmitted from a heat source to working fluid by heat exchangers and then finally to a heat sink. A Stirling engine system consists of at least one heat source, one heat sink, and up to five heat exchangers.

Heat Source
An external heat source (renewable or non-renewable) is used for heating the wall of the hot cylinder or the hot end of the cylinder which in turn expands the gas i.e. increases potential energy of the molecules of the gas, in order to cause movement in the piston. The heat source may be provided by the combustion of a fuel and, since the combustion products do not mix with the working fluid and hence do not come into contact with the internal parts of the engine, a Stirling engine can run on fuels that would damage other engines types' internals.
Other suitable heat sources include concentrated solar energy, geothermal energy, nuclear energy, waste heat and bioenergy. If solar power is used as a heat source, regular solar mirrors and solar dishes may be utilised.

Heat Exchanger
In low power engines the heat exchangers may simply consist of the walls of the respective hot and cold chambers, but where larger powers are required a greater surface area is needed to transfer sufficient heat. Typical implementations are internal and external fins or multiple small-bore tubes for the hot side, and a cooler using a liquid (like water) for the cool side.

Regenerator
A regenerator is a component in a Stirling engine that stores heat from one cycle so it can be used in the next cycle. Regenerators are often made of sheets of foil, steel wool, or a metallic sponge. The hot working gas flows over the regenerator (storing some of its heat there) on its way to the cold zone. When the cold gas returns, it flows back over the regenerator and is pre-heated before it goes to the hot zone. The result is higher power and more efficiency from a given Stirling engine.
The primary effect of regeneration in Stirling engine is to increase the thermal efficiency by 'recycling' internal heat which would otherwise pass through the engine irreversibly.

Heat sink
As we know greater the temperature difference between the hot and cold section of Stirling engine, the greater it's efficiency. A heat sink is basically an environment in which engine operates in, at ambient temperature. A heat sink is a component that increases the heat flow away from a hot device. It accomplishes this task by increasing the device's working surface area and the amount of low-temperature fluid that moves across its enlarged surface area.

Displacer
This is the part of the engine that moves or displaces the gas (working fluid) from the hot heat exchanger to the cold heat exchanger. Depending on the type of engine design, the displacer may or may not be sealed to the cylinder. In Beta and Gamma type Stirling engines the displacer is a special-purpose piston which is used to move the working gas back and forth between the hot and cold heat exchangers. When there is a temperature difference between upper displacer space and lower displacer space, the engine pressure is changed by the movement of the displacer. The pressure increases when the displacer is located in the upper part of the cylinder. The pressure decreases when the displacer is moved to the lower part of the cylinder. The displacer only moves the air back and forth from the hot side to the cold side.

Flywheel
Relative to the engine the flywheel is a large heavy wheel. It is mechanically connected to the piston of the engine. Its job is to add to the momentum of the machine and help carry the Stirling cycle all the way through. Most heat engines use a flywheel

IV. TYPES

There are major three types of Stirling engine differentiated by the way they displace the air between hot and cold areas.
Alpha

It is the type of Stirling engine in which 2 cylinders are used out of which one is the expansion cylinder or hot cylinder which is equipped with the heat source and another is the compression cylinder or cold cylinder which is having cooling device at its outer wall, these 2 cylinders are connected with a common passage through which the exchange of cold gas from the cold cylinder to the hot cylinder and hot gas from the hot cylinder to the cold cylinder takes place. Alpha Stirling engine is the low power engine and is used for light load applications.

Beta
It is the type of Stirling engine in which a single cylinder is used which is equipped with the heat source at the one end and a cooling device at another end. The exchange of hot and cold gas from hot end to the cold end and from cold end to the hot end is provided by the loosely fitted displacer, this displacer is connected to the crankshaft or the flywheel that controls its motion inside the cylinder. Beta Stirling engine is the high-power engine and is used for high load applications.

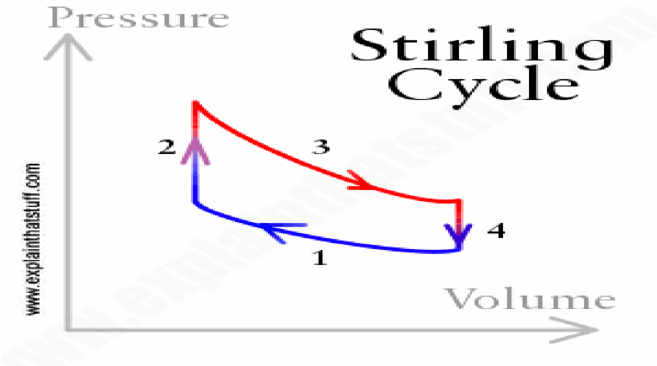
Gamma
This type of Stirling engine has a power piston and a displacer that are connected with two separate cylinders. The gas from the two cylinders flows freely between them and remains integrated. Due to the large volume of connection between the two cylinders, this structure has a lower compression ratio but has a simple design and is typically used in a multi-cylinder Stirling engine. It is suitable for low temperature difference Stirling engines that require a large amount of heat input.

Other Types
There are other types of Stirling engine like-
Rotatory Stirling Engine system described consists of multiple rotary units mounted together for a combined power output. Each rotary unit is comprised of an eccentric rotor, multiple vane rotary engine which is independent from adjacent units in a modular arrangement. Both internal and external regeneration techniques are utilized to improve overall performance and efficiency.

Fluidyne Engine which uses hydraulic pistons to implement the Stirling cycle. The work produced by a Fluidyne engine goes into pumping the liquid. In its simplest form, the engine contains a working gas, a liquid, and two non-return valves.
The Ringbom engine concept published in 1907 has no rotary mechanism or linkage for the displacer. This is instead driven by a small auxiliary piston, usually a thick displacer rod, with the movement limited by stops. It conceived a arrangement, with the disp1acer and piston operating in a single cylinder. The concept was attractive as the means to convert existing internal combustion engines to operate as Stirling cycle machines and hence reduce the development cost of large engines. the Double acting Stirling engine consists of 4 cylinders. by connecting the space on the upper and lower surfaces of adjacent pistons via a heat exchanger, the working space corresponds to 8 cylinders of a normal α Stirling engine. it is possible to miniaturize the engine, and it is a format suitable for high-power engines.

However, a disadvantage of this machine is that one connecting rod must have a sliding seal at the hot side of the engine, which is difficult when dealing with high pressures and temperatures

V. OPERATION Theory



A Stirling engine uses a different cycle that (ideally) consists of:

1. Isothermal (constant temperature) compression: Our stage (1) above, where the volume of the gas decreases and the pressure increases as it gives up heat to the sink.
2. Isovolumetric (constant volume) heating: Our stage (2) above, in which the volume of the gas remains constant as it passes back through the regenerator and regains some of its previous heat.
3. Isothermal (constant temperature) expansion: Our stage (3) above, in which the gas absorbs energy from the source, its volume increases and its pressure decreases, while the temperature remains constant.
4. Isovolumetric (constant volume) cooling: Our stage (4) above, in which the volume of the gas remains constant as it transfers through the regenerator and cools.

The Stirling engine works in the following way:

- As the operator turns on the engine starter, the external heat source also starts. The operator controls the force through the mechanism provided.
- When the external heat source is activated, the heat starts transforming from the heat source to the hot end of the cylinder. This process of heat transfer increases the gas molecules temperature trapped in the cylinder’s hot end. As the temperature of the gas molecules rises, a disturbance starts producing between them and gas molecules start expanding inside the cylinder.
- The gas expansion increases the pressure on the piston surface, pushes the piston away and generates useful work.
- A displacer piston is coupled with a crankshaft. The movement of the crankshaft causes the displacer piston to move between the cold end and hot end of the cylinder.
- The displacer piston’s movement causes a gas exchange from the cold end to the hot end and the hot end to the cold end of the cylinder.
- The hot end gas provides the power to the displacer

piston, which transfers the gas into the cold end of the cylinder.

- As the hot gas is entered into the cold end, the cooling device extracts the heat of the hot gas and cools it.
- After cooling the gas, the piston compresses the gas in the cold end of the cylinder. A cooling device removes the excess heat from the gas.
- After the compression process, the displacer piston sends the compressed gas back into the hot end of the cylinder, where the cycle repeats.

This is the working principle of the Stirling engine. As you can see above that, in this cycle, there is no exhaust stroke-like IC engine. Therefore, a Stirling engine has more efficiency than an internal combustion engine.

VI. APPLICATIONS

Stirling engines have multiple applications in different fields such as:

- Mechanical output and propulsion. These types of engines have been used in the automotive industry and in marine propulsion, among other examples. Compared to heat engines, good performance can be obtained.
- Power generation using nuclear power and solar power. In this case, there are applications related to nuclear energy and solar energy. In both cases, it is a question of using these resources as a heat source to drive a steam turbine.
- Stirling engines can work as a heat pump. Thanks to the heat exchanger of these systems and the fact that they are reversible.

VII. CONCLUSION

The Stirling engine is basically advantageous for its high efficiency compared to steam engines, quiet operation, and the ease with which it can use almost any heat source like from fossil fuels, solar power and most importantly waste heat reduction. It is very easy to install and required low maintenance 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.

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