The advantages and applications of the Stirling engine

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Abstract. Stirling engines are a kind of heat engine that achieve their function via compressing and expanding the working fluid at temperatures that are entirely different from one another. The Stirling cycle consists of four processes, two of which are isothermal and the other two are isochoric. Stirling engines may be assembled in one of three distinct configurations: alpha, beta, or gamma. They are superior to traditional heat engines, with high efficiency, low noise, and low pollution. Stirling engines may be found in various systems that produce power and those used for mechanical propulsion, heating and cooling, and other similar applications. In today's world, programs such as this are really helpful. On the other hand, they have some drawbacks, such as a low power density, a high price tag, a sluggish beginning-of-operation and reaction time, and restricted availability. This page covers a variety of topics pertaining to Stirling engines, including their history, composition, characteristics, applications, and use, as well as some of the likely next advancements in the field.

Keywords: Stirling Engine, Thermodynamics, Stirling Cycle.

1. Introduction

Robert Stirling was born in 1790 in Perth Shire, Scotland. He was an artificer of the Stirling engine [1]. Stirling engine is a sort of heat engine. His company factory-made engines from 1818 to 1922. Throughout this time, they used the Stirling engine to pump water on farms and generate electricity. Stirling engines are divided into 3 types: alpha, beta, and gamma configuration engines. Though they appear slightly completely different, all of them add identical meanings. Visually, the Alpha engine has 2 pistons in separate cylinders. Each Beta and Gamma engine has a dis-placer-piston configuration, with the Beta engine having the dis-placer associate piston in an in-line cylinder system, whereas the Gamma engine uses separate cylinders [2]. They have several advantages over conventional heat engines, such as high efficiency, which can theoretically achieve Carnot performance, low noise, and low pollution because the Stirling engine can use a renewable heat source.

Stirling engines are used in several mechanical propulsion, heating and cooling, and power production systems. However, they have several problems in common, such as poor power density, high cost, slow start-up and response times, and limited availability. This article discusses probable future advances for Stirling engines and their history, composition, features, usage, and applications.

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2. The working mechanism of the Stirling engine

2.1. Components

A Stirling engine comprises cylinders, pistons, gas, an outside heat source, a cooling system, a crankshaft, and a rotor. The Stirling engine has either one or two cylinders. The cylinders are connected by a passageway that lets the gas run from the hot cylinder to the cold cylinder so it can be used again. The pistons determine the end amount of power an engine makes. The fluid that makes the Stirling engine work is gas. This gas is used in the cylinder so that the compression and expansion of the gas in the cylinder move the pistons back and forth. A heat source from the outside is used to heat the current cylinder's wall or the current cylinder's current end. This causes the gas to expand, increasing the gas molecules' pressure and moving the piston. After the cylinder wall has been heated, the cooling device is used to cool it down. The crankshaft helps move the piston's mechanical work to the flywheel. The crankshaft stores the engine's output for further transmission [3].

2.2. Cycle

The Stirling cycle is a thermodynamic cycle that describes a Stirling engine. It consists of four processes: two isothermal processes and two constant-volume processes. The Stirling cycle can be represented by a pressure-volume PV diagram or a temperature-entropy TS diagram (Figure 1). Process 1 to 2 is the accumulation of isothermal heat. The gas is elevated to a constant temperature by an external heat source. Work is performed on the piston. The second to third step is constant volume heat rejection. The regenerator transfers the gas from the hot cylinder to the cold cylinder. The regenerator reduces heat energy released to the environment and increases the cycle's efficacy. Three to four are isothermal heat rejection processes. The gas is cooled to a constant temperature by an external heat absorber. Work is performed on the piston. Process 4 to 1 is the addition of heat at a constant volume. The regenerator transfers the gas from the cold cylinder to the hot cylinder. It returned the heat from step 2 to step 3 [4].

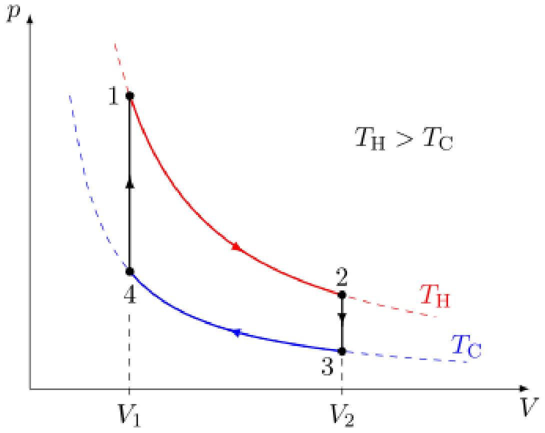

Figure 1. The P-V diagram of the Stirling cycle, reproduced from the website: https://en.wikipedia.org/wiki/Stirling_cycle.

3. The significance and applications of the Stirling engine

3.1. Applications

The main applications of Stirling engines are mechanical output and propulsion, electric generation, and heating and cooling systems. The Stirling engine has many applications in engines and vehicles for mechanical output and recommendation. Stirling engines as part of a hybrid electric propulsion system can circumvent the design difficulties or disadvantages of a non-hybrid Stirling automobile. In November 2007, the Swedish Precer project unveiled a hybrid vehicle prototype powered by solid biofuel and a Stirling engine. Stirling engines could be an option for submerged power systems that call for sporadic or continuous action on the electrical or mechanical front. Using solar power and the Stirling cycle, Stirling engines driven by the sun can pump water from bodies such as rivers, lakes, and streams. They can irrigate crops in areas of the world that are dry and sparsely populated yet have not yet been developed. There is a possibility that Stirling engines driven by nuclear energy might one day be used in power plants.

The substitution of Stirling engines for steam turbines in nuclear power plants can streamline the facility, enhance operational efficiency, and reduce the production of radioactive waste materials. Solar energy conversion into electricity may be effectively achieved using a photovoltaic array Stirling engine positioned at the focal point of a parabolic mirror [5]. The Stirling engine can operate in reverse, serving as a heat exchanger for heating and cooling. Philips Corporation of the Netherlands efficiently used the Stirling cycle in cryogenic applications during the late 1930s. Numerous experimental investigations have been undertaken to explore using wind energy to power a Stirling cycle heat pump, specifically facilitating domestic heating and cooling.

3.2. Unique merits

Stirling engines have many notable benefits, including ease of maintenance, reduced noise emissions, enhanced efficiency, favorable performance in low-temperature conditions, and the ability to use a wide range of fuels. The reduction in wear, lubrication needs, and maintenance is attributed to the absence of direct contact between the flammable gas mixture and the moving mechanical components. The Stirling engine has a structural simplicity due to its absence of valves and combustion mechanisms. The vibrations produced by the created system are easier to manipulate and exhibit a notably reduced noise level compared to those generated by an internal combustion engine. The Stirling engine is the only engine with the potential to approximate the Carnot performance, representing the theoretical maximum performance achievable by any thermal engine. The Stirling engine can theoretically attain the Carnot performance, making it the optimal choice for thermal engine performance [6]. The Stirling engine has favorable performance in conditions characterized by low temperatures. The performance of this alternative engine surpasses that of internal combustion engines in freezing temperatures, while the latter is known to run well in moderate temperatures but has difficulties in colder conditions. The Stirling engine can function with various heat sources, such as wood, coal, gas, biogas, liquid fuels, solar, and nuclear energy. In contrast, internal combustion engines are limited to operating on petroleum [7].

4. Issues and future development

4.1. Environmental problems

The Stirling engine has two main environmental problems: heat source availability and loss of heat. Stirling engines require a heat source and a heat absorber, which may not be readily available or accessible in certain locations or circumstances. For instance, solar energy may not be sufficient or consistent in cloudy or rainy regions, biomass may not be abundant or renewable, and waste heat may not be readily captured or utilized in certain processes. In addition, the heat source and drain may have environmental impacts, such as greenhouse gas emissions, land use, and water usage [8]. Stirling engines involve heat transfer between external sources, sinks, and the internal working fluid, resulting in losses due to thermal resistance, conduction, convection, radiation, etc. These losses reduce the engine's efficiency and power output, increasing the required operating temperature differential. Utilizing efficient and durable heat exchangers, optimizing the engine, and employing high-pressure working fluids such as hydrogen or helium can minimize heat transfer losses.

4.2. Disadvantages

There are some disadvantages of the Stirling engine. Stirling engines are more common and hefty. The external combustion of the Stirling engine, which necessitates heat exchangers at both hot and cold locations, makes the Stirling engine more cumbersome than an internal combustion engine with the same output power due to the necessity of heat exchangers at both hot and cold locations. Second, Stirling engines are extremely expensive. Inlet and outlet heat exchangers for Stirling engines must contain a high-temperature working fluid and resist the heat source and the environment. This requires the use of materials that have a significant impact on the machine. They have a delayed commencement time, thirdly. An external combustion engine's inherent thermal inertia makes its ignition more difficult. The Stirling engine is, therefore, inappropriate for applications requiring rapid acceleration or speed variations. The final disadvantage is that Stirling engines are riskier. Due to oxygen in the air, the air mixture and combustible lubricating fluids within the engine can generate explosive mixtures; this hazard is exacerbated in high-pressure engines. The issue was resolved by reducing neutral working gases or without conventional lubricants [9].

4.3. Future trends

There are still numerous modifications for the Stirling engine's future development. The first step is to increase the use of Stirling engines in renewable energy applications, such as concentrated solar power, biomass, and waste heat recovery. Stirling engines benefit from using any heat source, as well as being highly efficient and emitting few pollutants. They can also be combined with thermal storage devices or hybrid systems to increase stability and operation time. Then, the reliability of Stirling engines must be enhanced by developing new materials and coatings for the heat exchangers and regenerators, optimizing the engine's geometry and parameters, implementing advanced control strategies and sensors, etc. These enhancements can assist in overcoming the drawbacks of Stirling engines, such as low power density, high cost, sluggish start-up and response time, and complex heat exchangers. It is desired to investigate new applications and markets for Stirling engines, such as rural areas, remote areas, and developing nations. Stirling engines can provide mechanical power, heating, cooling, and electricity for various applications, including water circulation, refrigeration, air conditioning, etc. They can also be utilized as reserve power or peak reduction in emergencies or high-demand situations [10].

5. Conclusion

In 1816, a Scottish priest named Robert Stirling produced the idea for what would become known as the Stirling engine. He wanted to build a more reliable alternative to the steam engine. Alpha, Beta, and Gamma are the names of the three types of Stirling engines used today. Even though different engine types seem quite different, the fundamentals behind how they work are the same. They all repeatedly heat and cool a certain amount of gas inside an enclosed system to carry out their functions.

The components that make up a Stirling engine are as follows: cylinders, pistons, gas, an external source of heat, a cooling system, a crankshaft, and a rotor. The functioning of a Stirling engine may be characterized by using what is known as the Stirling cycle. It comprises two isothermal processes and two processes that maintain a constant volume. A pressure-volume or temperature-entropy diagram may show the Stirling cycle in action. In addition, Stirling engines may be used in a wide variety of contexts, including the production of mechanical output and propulsion, the creation of electric power, and the operation of heating and cooling systems. In addition to this, the Stirling engine offers many significant benefits. They are easier to maintain, quieter, more effective, sensitive to low temperatures, and fuel-flexible. Additionally, they are more effective. Stirling engines, on the other hand, have many significant drawbacks, such as being expensive, risky, and difficult to maintain. Challenges associated with the Stirling engine include the availability of heat sources and heat loss. The Stirling engine has the potential to be used in producing energy from a wider variety of renewable sources, improve dependability, and open up new applications and market spaces.

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