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Electromechanical Problems and Solutions in Heat Engines

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Abstract Stirling engines are produced in many different ways according to their production types. The main purpose is to produce more efficient, high performance, stirling engines with different designs. In other words, an effort has been made to achieve optimum performance by producing ideal heat engines. Nowadays, many heat engines, also known as stirling engines, have been developed for energy production. The working logic of all Stirling engines is similar. In this study, the problem of design leakage and the dead volume which reduces efficiency in the production of Stirling engines is analyzed. Solutions have been tried to be produced for design problems.

Keywords Thermodynamic cycle, heat engines, electro mechanic, stirling

1. Introduction

Stirling engines that work with a difference in heat are called heat engines. In this study, the heat engine is a stirling engine. Stirling motors operate according to the principle of external heat dissipation. They comprise a drive mechanism, a heater, a regenerator, a cooler, a power piston, a piston and a block of the engine. Regardless of type, heater, regenerator and cooler are the main parts of stirling engines. The task of the movement mechanism is to perform the thermodynamic cycle by moving the piston and displacer in a timely manner with each other. In Stirling engines the sun is collected on a receiver. It converts the radiation from the sun into heat by means of the receiver focuser and provides the transfer of heat to the gaseous material such as air, helium or hydrogen [1-5].

Positive aspects about heat engines; all kinds of heat sources are used, low production costs, easy to install and maintain, they can be manufactured as very small or very large, they work silently, long economic life, and they do not pollute the environment [5-8].

Negative aspects about heat engines; it takes time for the motor to decelerate and accelerate, the speed control of the piston is difficult, heat-resistant high-cost materials are used due to the high temperature, dead volumes reduce engine efficiency, the sealing problem should be solved, therefore, gas leaks occur and engine efficiency decreases, the engine starts slowly and over time, the engine piston and the engine accelerate [7-9].

2. Exchange Stages of Heat Engines

Heat engines are also known as Stirling engine. Stirling motors are theoretically the most efficient motors. With their silent and vibration-free operation, they can be used without the need for a special fuel or energy source, with the power values produced and their simple designs, these engines are also used in solar energy systems today.

The Stirling engine (heat engine) was invented in 1816 by patent number 4081, Robert Stirling. Stirling engines are simple to operate and safe. They operate quietly and are popular because they are more efficient than steam engines. The first generation of stirling motors produced electricity between 100 W and 4 kW [7-10].This

engine was used in 1818 to pump water from a quarry. This engine includes a power piston, a displacer that moves air between the hot and cold zones, and a regenerator [10-12].
In order to increase the power of Stirling engines, in 1820 Robert Stirling and his brother James Stirling attempted to increase the amount of gas used by applying pressure fillers. Until the 1850s, Robert Stirling produced two- and three-cylinder engines of the displacer type, but their performance was not as high as the first. The low performance of the subsequently manufactured engines is attributed to the high dead volume of these engines [10,11].
In 1853, John Ericsson manufactured a stirling engine for watercraft with a 4.2 m diameter piston producing 220 kW at 9 rpm. In the 1860s, a single-cylinder displacer engine was built by Lehman in Germany and achieved very good results even though it did not use a regenerator. The production of these engines continued until 1915 and did not exceed 7% [9-12, 13-15]. Stirling engine first period has stopped with the presence of internal combustion engine and the rapid development of the electric motor.

3. Electromechanıcal Workıng Prıncıples in Heat Engınes

Stirling engines are produced in many different types from the past to the present according to their types. The operating logic for all Stirling engines is similar. Changes have been made in the design to solve the problems in heat engines. For example, different designs have been produced to reduce the problem of sealing and dead space.
Stirling engines mechanically;

- Single-acting heat engines
- Double-acting heat engines

they are classified as [9-15].

3.1. Single-Acting Heat Engines

In Stirling engines, these engines are called single-acting as the pressure in the engine acts in one direction of the piston. Single-acting Stirling engines consist of compression, expansion and regenerator. The elements operating in the cylinder can both be pistons. Or a piston can be a displacement piston. A crank mechanism or a separate movement mechanism can also be used [34]. Single-acting Stirling engines can be grouped into three groups. These are alpha, beta and gamma types.

3.1.1. Alfa Heat Engines

As shown in Figure 1, this engine has two separate power pistons. One of the pistons operates in the cylinder on the hot side and the other piston operates in the cold cylinder. The connection between the two cylinders is achieved by means of a series connected regenerator. Since the hot cylinder and the cold cylinder are in different regions, there is no thermal transfer side heat transfer. The superiority of the alpha stirling engine is that it has high power / volume ratios. Alpha stirling engine has two disadvantages;

- Sealing problem on the heated piston side
- loss of power due to excess dead volume

The Alfa stirling engine has to operate at low temperatures due to the sealing problem. For this reason, it is used in systems such as refrigerators and heat pumps [15-20].

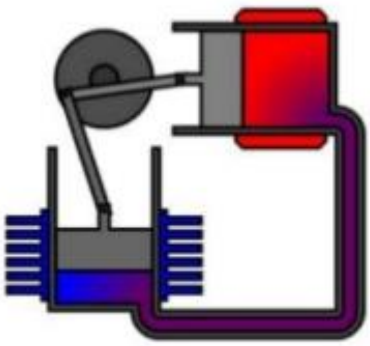

Figure 1: Alpha-type Stirling engine [20-24]

3.1.2. Beta Heat Engines

Beta-type Stirling engines consist of a synchronous displacement and power piston in a cylinder. The displacement piston allows the movement of gases with working fluid. In other words, it pushes the hot working fluid away from the heating point to cool it. In Beta-type Stirling engines, one end of the chamber, called displacer, displacement piston or cylinder, is heated, while the other end is cooled. Heating and cooling processes are made from the cylinder wall. One end of the cylinder is heated while the other end is cooled; in this way, higher power generation can be achieved with a temperature difference. For this purpose, some methods can be used, such as insulation to reduce thermal interaction between the hot and cold ends in the cylinder. The most important advantage of the Beta-type Stirling engine system is that the pistons support each other so that high compression force can be achieved [20-24].

As shown in Figure 2, in the beta-type Stirling engine, the cylinder volume consists of two discrete volumes with the displacement piston. The gases in the volumetric area on the displacement plunger are subjected to heating to ensure the expansion of the gas. Specifies the volumetric area of volumetric compression between the displacement piston and the power piston. Here, too, any type of gas used as working fluid is subjected to cooling. As long as the Stirling engine is running in the heating and cooling compartments, heating and cooling continue uninterruptedly [20-24]. Figure 6 shows beta-type Stirling motor prototype.

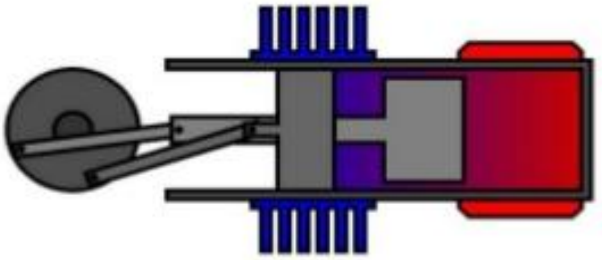

Figure 2: Beta-type Stirling motor prototype and displacer block [20-24]

As shown in Figure 3, during the initial compression phase 1-2, the majority of the working fluid is in the cold zone. When the power piston is first moved, the fluid is compressed in the cold zone under the influence of the pushing force.In 2-3 constant heating volumes, the gas in the cold zone fills the hot zone through the regenerator channel due to the pressure increase at the end of the compression. In this transition, heat transfer occurs from the regenerator to the working fluid. In this case, the working fluid whose temperature increases, expands, causing the displacement piston to move towards the lower end. In the meantime, since the power piston is at the upper end, the gas in the cold zone continues to compress. The momentary displacement piston is at the lower end while the power piston is at the upper end. During this very short period of time, almost all of the working fluid is located in the hot zone. In this phase, there is no volume change in the cylinder since only the displacement piston moves.

In the 3-4 expansion process, the force piston moves from the upper end to the lower end with the effect of the pressure force formed in the cold zone. As the volume increases during the expansion phase, the pressure decreases.

4-1 In the constant volume cooling phase, as a result of the movement of the movement piston from the lower position to the upper end position, the gases filling the hot zone are filled into the cold volume by the effect of spring forces. During passage through the regenerator, heat is transferred from the working fluid to the regenerator. The heat supplied to the regenerator is transferred to the working fluid during the 2-3 cycles of the next cycle. When the displacement piston reaches the upper end, almost all of the working fluid is located in the cold zone. Since only the movement piston is displaced during the process, the cylinder volume does not change and cooling takes place at a constant volume. As with other engines, the first movement is given from the outside to start the engine. Figure 3 shows the beta-type Stirling motor motion stages.

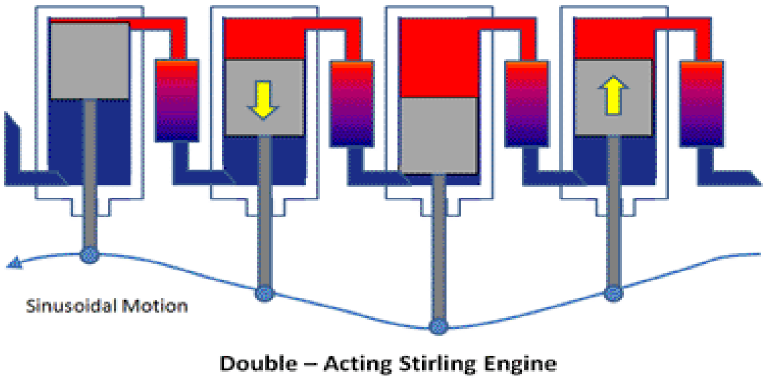

Figure 3: Beta-type Stirling engine motion stages [20-24]

3.1.3. Gamma Type Heat Motors

As shown in Figure 4, gamma-type Stirling engines have a displacement and a power piston mechanism similar to a beta engine. Unlike the Beta-type Stirling engine, the pistons are not concentric to each other. The cylinders operate in parallel with each other. This design is designed to maximize dead volume. The first cylinder compresses and expands the working fluid while reducing and increasing the working volume. The other cylinder cools and heats the working fluid with the displacement piston. The advantageous aspect of the gamma-type Stirling engine design is its simple mechanical design. The disadvantage of this motor is its low compression ratio.

A gamma-type Stirling engine requires a displacement and a piston. The working fluid is heated and cooled to a constant volume within the displacement piston of the gamma-type Stirling engine. In this way, the total volumetric area in which the working fluid is located in the power cylinder is narrowed. As a result, the hot gas in the power cylinder passes into the cold zone of the displacement cylinder. When the return period is complete, most of the working fluid is located in the cold zone of the displacement cylinder. The volume of the working fluid remains constant during this process.

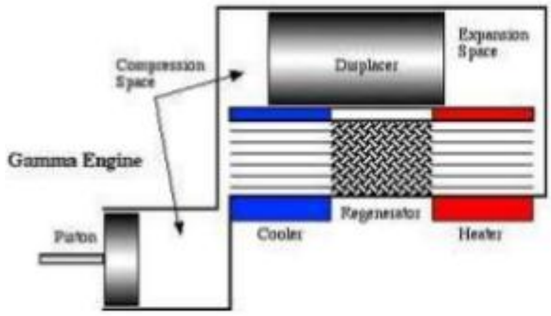

Figure 4: Gamma-type stirling motor [20-24]

3.2. Double Acting Heat Motors

In Stirling engines, since the pressure in the engine affects both directions of the piston, these engines are called double acting. In double-acting Stirling engines, the number of cylinders is equal to the number of engines. Double-acting Stirling engines are also available in many designs. In such Stirling engines, a regenerator is placed between the expansion volume of the cylinder and the compression volume of the other cylinders. The biggest advantage of double-acting motors is that they have fewer parts than single-acting Stirling motors [20-25].

3.2.1. Double Acting Franchot Heat Engine

Figure 5 shows the principle scheme of a double-acting FranchotStirling engine. The two pistons are limited to four discrete regions. Two separate alpha machines can be thought of as working. As with the Alpha machine, a phase angle of approximately 90 ° is required between the expansion and compression pistons. The sealing of the piston rod operating on the hot side is problematic in this engine [20,25,26].

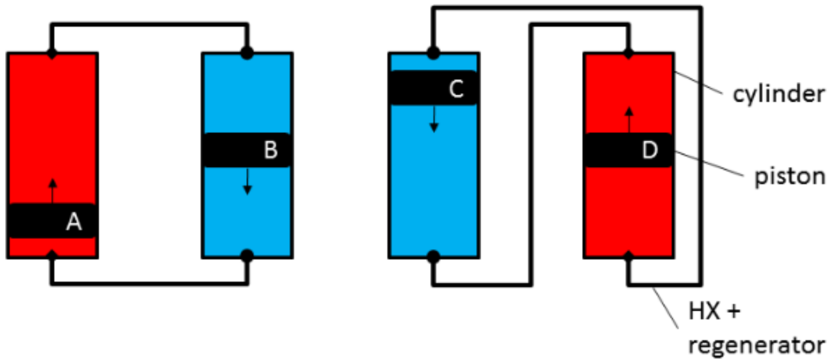

Figure 5: The principle scheme of a double-acting FranchotStirling engine [20,25,26]

3.2.2. Double Acting Siemens Heatengine

Designed by Sir William Siemens in 1863, the engine was re-developed by Weenan in 1940. Today's high-performance Stirling engine principles are based on the Weenan approach. Only one side of the piston has a compression chamber. The compression chamber, also called the cold chamber, ensures that the seal is at a low temperature. The Siemens Stirling engine is double-acting, and has the advantage of being compared to other stirling engines with the ability to form a seal in the cold zone. In this way, it is possible to obtain high powers with Siemens Stirling motor. When the double-acting Siemens Stirling engine is examined, it is seen that this engine consists of a combination of alpha-type Stirling engines [20,25,26].The double acting siemensstirling motor is shown in Figure 6.

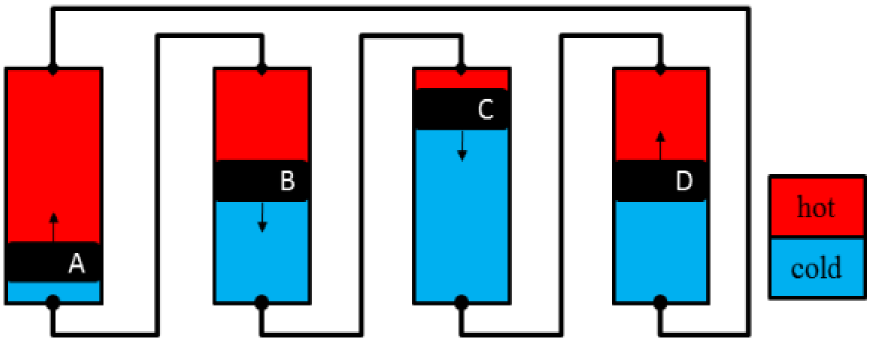

Figure 6: The double acting siemensstirling motor [20,25,26]

3.2.3. Free Piston Heat Engine

In such motors, the power piston has no mechanical connection to the displacement piston and other metal parts. The pistons can move freely and the converted energy can be transmitted with the help of a regenerator, a heat exchanger (heat conduction) or other methods. In principle, all Stirling engines can be converted into a free piston engine. Low temperature changes and pressure changes occur in the free piston Stirling engine to vibrate the piston occurs [20, 27-33]. Figure 7 shows mechanism of free-piston Stirling engine.

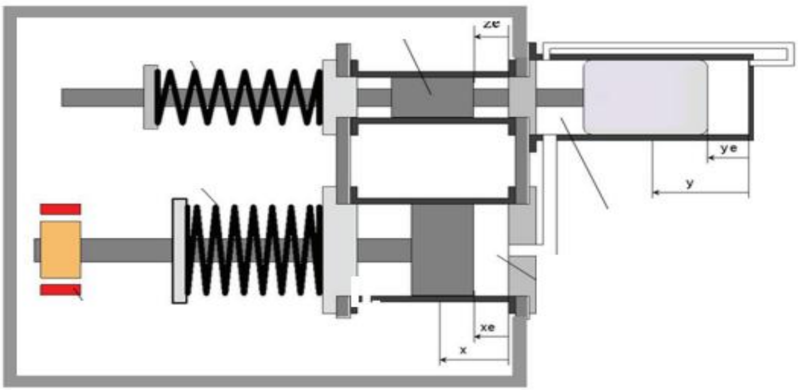

Figure 7: Mechanism of free-piston Stirling engine [20,27]

3.2.4. Liquid Piston Heat Engine

There is a mixture of air and water vapor at the top of a system made of glass tube. On the left side of this system, which is made of glass tube, air is heated and on the right side, cooling is performed. The machine is heated by an external source to ensure the movement of the liquid fluid. In the meantime, the air between the hot chamber and the cold chamber is drawn through the connecting pipe towards the hot cylinder. The heated air in the hot cylinder increases the pressure in the whole system. The pressure increase moves the power piston downwards. To complete this cycle, the flow of water from the cold chamber to the hot chamber continues with the pushing effect of the displacement. This reduces the system pressure by cooling the air in the cold cylinder. In order to compensate for the pressure drop, the power piston moves backwards by itself and continues to operate. If the heating operation continues and no energy is drawn, the oscillation movement accelerates and continues [34,35]. The double acting liquid piston stirling engine is shown in Figure 8.

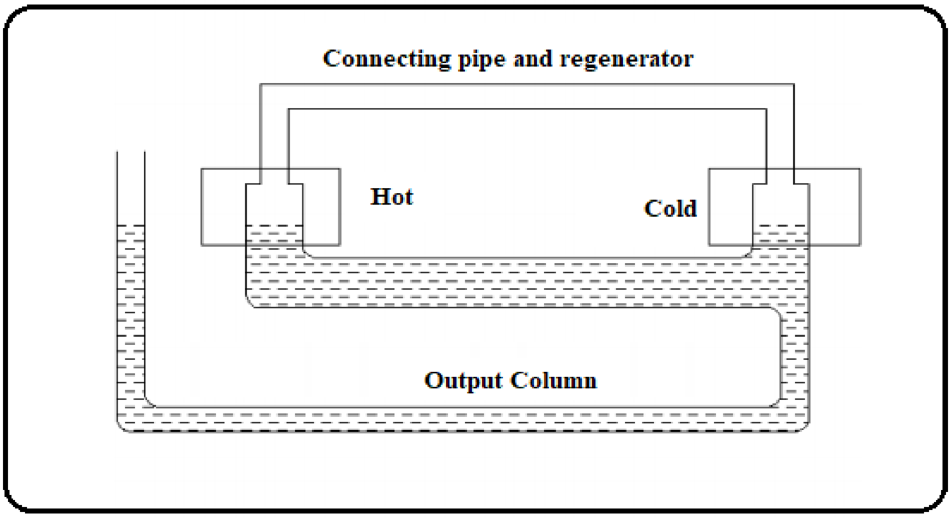

Figure 8: The double acting liquid piston stirling engine [34,35]

4. Results

Stirling motors are produced according to their production types as single-acting or double-acting stirling motors. Single-acting stirling motors are classified as alpha, or gamma type motors. Some of the double-acting stirling engines are classified as double-actingFranchot, double-acting Siemens, double-acting free piston and double-acting liquid piston.

According to the analysis, it was found that each stirling engine (heat engine) had an advantage according to its location and position.

In addition, each stirling engine has been found to be advantageous at one point and disadvantageous at several points. Therefore, each heat engine should be considered as a special solution for every problem.

However, such a design-induced leakage problem and the dead-volume event, which reduces efficiency, can be reduced.

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