A Review on Sterling Engine

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Abstract— The Sterling engine is a device that allows conversion of thermal energy into mechanical energy with relatively high efficiency. Existing commercial designs are mainly based on the usage of high temperature heat sources, whose availability from renewable or waste heat sources is significantly lower than that of moderate temperature sources. The paper presents the results of experimental research on a prototype alpha type Sterling engine powered by a moderate temperature source of heat. Obtained results enabled calibration of the evaluated theoretical model of the Sterling engine. The model of the engine has been subsequently used for the analysis of regenerator effectiveness influenced by the charge pressure and the heating temperature. Performed study allowed determining further development directions of the prototype engine to improve its power and efficiency. As a result of optimization, worked out design will potentially increase the indicated efficiency up to 19.5% (5.5% prototype) and the indicated power up to 369 W (114 W prototype).

Keywords: Sterling Engine; Renewable Energy Sources; Moderate Temperature; Adiabatic Model

I. INTRODUCTION

The Sterling engine is based on simple concepts. In fact, the Sterling cycle engine was conceived More than 80 years before the Diesel and Otto cycle engines. Since its conception, the Sterling Engine has been recognized for its potential to attain high cycle efficiencies; however, it has Failed to reach its full potential due to design challenges such as seals, materials, heat transfer, Size, and weight. In the past 200 years, individual inventors and corporate research laboratories have produced scores of technical and patent literature on thousands of Sterling engine designs. [1] The Sterling engine is noted for its high efficiency compared to steam engines, quiet operation, and the ease with which it can use almost any heat source. This compatibility with alternative and renewable energy sources has become increasingly significant as the price of conventional fuels rises, and also in light of concerns such as peak oil and climate change. This engine is The Sterling engine is noted for its high efficiency compared to steam engines, quiet operation, and the ease with which it can use almost any heat source. This compatibility with alternative and renewable energy sources has become increasingly significant as the price of conventional fuels rises, and also in light of concerns such as peak oil and climate change. 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. [2] The Sterling engine uses an external heat source to heat the working substance. The heat source can come from burning fossil fuels, solar energy, decaying plant matter, or whatever is available. In fact, all the Sterling engine requires to operate is a temperature difference. It is possible to run a Sterling engine by cooling one region of the engine below ambient temperature. The gas inside the cylinder of a Sterling engine is not burned or consumed in anyway. Hence, in contrast to the internal combustion engine, the Sterling engine does not require an exhaust or an intake. If a clean external heat source is used with the Sterling engine, it can be an environmentally friendly alternative to engines that burn and emit hydrocarbons and other pollutants. [3] Sterling engines limit noise pollution because they do not require intake and exhaust valves which usually are the main source of engine noise. However, Sterling engines that would be suitable for automobile use are larger, heavier, and more expensive than conventional internal combustion engines. Moreover, Sterling engines require some time to warm up before they start and the output of the engine cannot be changed quickly for quick acceleration and deceleration. [4]

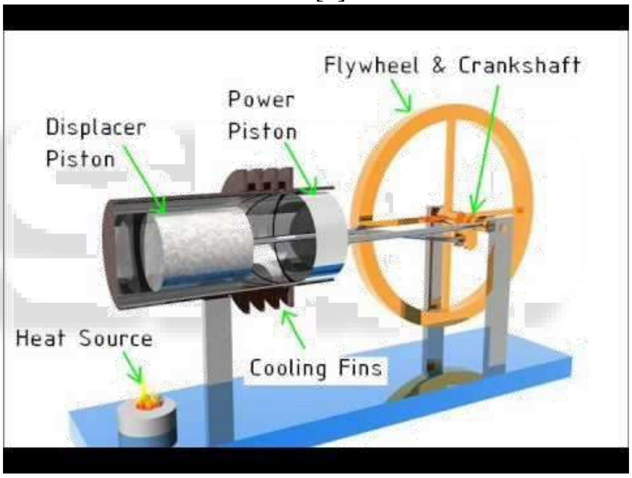

Fig. 1: Mechanism of sterling engine

II. LITERATURE REVIEW

The major types of Sterling engines that are distinguished by the way they move the air between the hot and cold areas:

A. Alpha Configuration Operation:-

An alpha Sterling contains two power pistons in separate cylinders, one hot and one cold. The hot cylinder is situated inside the high temperature heat exchanger and the cold cylinder is situated inside the low temperature heat exchanger. This type of engine has a high power-to volume ratio but has technical problems due to the usually high temperature of the hot piston and the durability of its seals. In practice, this piston usually carries a large insulating head to move the seals away from the hot zone at the expense of some additional dead space. The crank angle has a major effect on efficiency and the best angle frequently has to be found experimentally. An angle of 90° frequently locks.

The following diagrams do not show internal heat exchangers in the compression and expansion spaces, which are needed to produce power. A regenerator would be placed in the pipe connecting the two cylinders.

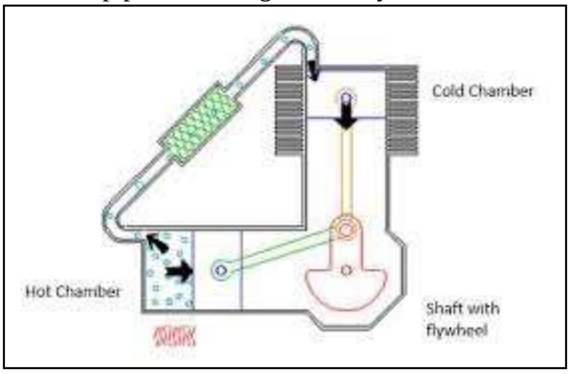

Fig. 2: Alpha type Sterling

B. Beta Configuration Operation

A beta Sterling has a single power piston arranged within the same cylinder on the same shaft as a displacer piston. The displacer piston is a loose fit and does not extract any power from the expanding gas but only serves to shuttle the working gas between the hot and cold heat exchangers. When the working gas is pushed to the hot end of the cylinder it expands and pushes the power piston. When it is pushed to the cold end of the cylinder it contracts and the momentum of the machine, usually enhanced by a flywheel, pushes the power piston the other way to compress the gas. Unlike the alpha type, the beta type avoids the technical problems of hot moving seals. The regenerator is placed in the gas path around the displacer. If a regenerator is used in a beta engine, it is usually in the position of the displacer and moving, often as a volume of wire mesh.

C. Gamma Configuration Operation

A gamma Sterling is simply a beta Sterling in which the power piston is mounted in a separate cylinder alongside the displacer piston cylinder, but is still connected to the same flywheel. The gas in the two cylinders can flow freely between them and remains a single body. This configuration produces a lower compression ratio because of the volume of the connection between the two but is mechanically simpler and often used in multi-cylinder Sterling engines.

D. Rotary Sterling Engine

The rotary Sterling engine seeks to convert power from the Sterling cycle directly into torque, similar to the rotary combustion engine. No practical engine has yet been built but a number of concepts, models and patents have been produced for example the Quasiturbine engine.

The hybrid between piston and rotary configuration is a double acting engine. This design rotates the displacers on either side of the power piston

Another alternative is the Fluidyne engine (Fluidyne heat pump), which uses hydraulic pistons to implement the Sterling 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.

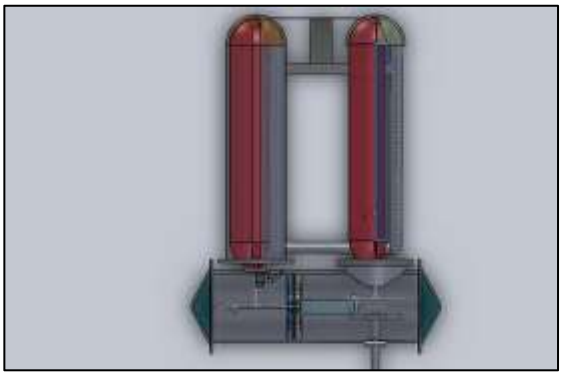
Fig. 3: Top view of two rotating displacer powering the horizontal piston. Regenerators and radiator removed for clarity

E. Ringbom Engine

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.

The two-cylinder Sterling with Ross yoke is a two cylinder Sterling engine (not positioned at 90°, but at 0°) connected with a special yoke. The engine configuration/yoke setup was invented by Andy Ross (engineer).

F. Franchot Engine

The Franchot engine is a double acting engine invented by ‘Franchot’ in the nineteenth century. A double acting engine is one where both sides of the piston are acted upon by the pressure of the working fluid. One of the simplest forms of a double acting machine, the Franchot engine consists of two pistons and two cylinders and acts like two separate alpha machines. In the Franchot engine, each piston acts in two gas phases, which makes more efficient use of the mechanical components than a single acting alpha machine. 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 a difficult task when dealing with high pressures and high temperatures.

G. Free piston Sterling Engines

Free piston Sterling engines include those with liquid pistons and those with diaphragms as pistons. In a “free piston” device, energy may be added or removed by an electrical linear alternator, pump or other coaxial device.

This avoids the need for a linkage, and reduces the number of moving parts. In some designs, friction and wear are nearly eliminated by the use of non-contact gas bearings or very precise suspension through planar springs.

Four basic steps in the cycle of a “free piston” Sterling engine are:

1) The power piston is pushed outwards by the expanding gas thus doing work. Gravity plays no role in the cycle.
2) The gas volume in the engine increases and therefore the pressure reduces, which causes a pressure difference across the displacer rod to force the displacer towards the hot end. When the displacer moves the piston is almost stationary and therefore the gas volume is almost constant. This step results in the constant volume cooling process, which reduces the pressure of the gas.

3) The reduced pressure now arrests the outward motion of the piston and it begins to accelerate towards the hot end again and by its own inertia, compresses the now cold gas, which is mainly in the cold space.
4) As the pressure increases, a point is reached where the pressure differential across the displacer rod becomes large enough to begin to push the displacer rod (and therefore also the displacer) towards the piston and thereby collapsing the cold space and transferring the cold, compressed gas towards the hot side in an almost constant volume process. As the gas arrives in the hot side the pressure increases and begins to move the piston outwards to initiate the expansion.

III. Material Review

Sterling engine based combined heat and power units are considered best among the most effective low power range thermal electricity and heat conversion units. The power pistons are used in sterling engine. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder. An internal combustion engine is acted upon by the pressure of the expanding combustion gases in the combustion chamber space at the top of the cylinder. This force then acts downwards through the connecting rod and onto the crankshaft. The connecting rod is attached to the piston by a swiveling gudgeon pin.

In micro-CHP system the heat exchangers are used for two purposes, one use to heat water and another for space or air heating. Normally there are two separate heat exchangers build in the one unit to serve two purposes. For water heating primarily the water circulated through the engine cavities which cool engine components by receiving heat from engine. For further heating of water the water circulated to a heat exchanger where engine exhaust gases are used for water heating. The exhaust gases from the auxiliary burner are directed into the exhaust heat exchanger where heat is transferred to the heating water. These heat exchangers are tube and shell heat exchangers.

The closed Sterling cycle makes it possible to use a working gas, which is better suited for heat transfer to and from the cycle than air. The helium or hydrogen is the most suitable gas for Sterling engines. The advantages of Sterling Engines are

1) Engine works on external combustion principal so any solid, liquid or gaseous fuels can be used.
2) The engine can use bio fuels so the system is eco-friendly.
3) Low emissions levels because of controlled combustion.
4. Low maintenance of the engine system because of less moving parts in engine.

A. Working:-

The Sterling engine works on the closed thermodynamic regenerative cycle The cycle consist four processes namely isothermal compression and expansion and isentropic heat addition and rejection processes. Consider a cylinder containing pistons with a regenerator between the pistons. The regenerator is like a thermal sponge alternatively absorbing and releasing heat, it is a matrix of finely-divided metal in the form of wires or strips. The volume between regenerator and the right side piston is expansion volume and between regenerator and left side piston is compression volume. Expansion volume is maintained at high temperature and compression volume is maintained at low temperature. The temperature gradient of (Tmax -Tmin) between the ends of regenerator is maintained.

To start with a cycle we assume that the compression space piston is at outer dead point (at extreme right side) and the expansion space piston is at inner dead point close to regenerator. All working fluid is in the cold compression space. The working fluid is compressed in the compression space and the pressure increases from P1 to P2. The temperature is maintained constant due to heat flow from cold space to surrounding. Work is done on the working fluid equal in magnitude to the heat rejected from the cycle. There is no change in internal energy and there is a decrease in entropy. Isothermal compression of the working fluid involving heat transfer from working fluid to external dump at Tmin

$$\mathrm{P2} = \frac{\mathrm{P1V1}}{\mathrm{V2}} = \mathrm{P1Rv}$$

$$\mathrm{T1} = \mathrm{T2} = \mathrm{Tmin}$$

$$\text{Heat transfer Q} = \text{Work done W},$$

$$\mathrm{Qr} = \mathrm{W} = \mathrm{P1V1ln(1/Rv)}$$

$$\text{Change in entropy} = (s2 - s2)$$

$$\delta = \mathrm{VD/VSW}$$

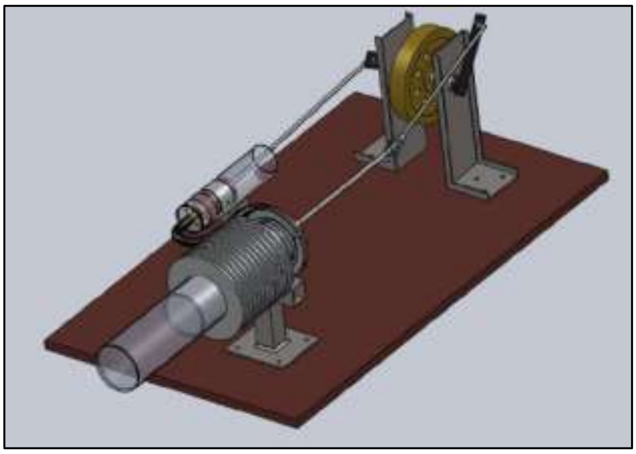

Fig. 4 Experimental Setup

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