

# SPECIFICS OF STIRLING ENGINE WITH RECUPERATION HEAT EXCHANGER

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**Abstract:** Recent research of Stirling engine at the Aeronautical Institute of Riga Technical University has focused on a new modification of Beta type Stirling engine. The modification was developed by scientists of the Aeronautical Institute and now the prototype of this modification is in the design phase. The new modification has recuperation heat exchangers and many different constructive versions were investigated and optimized. This paper explains the design philosophy behind the new engine modification.

**Keywords:** STIRLING ENGINE, NEW CONFIGURATION OF ENGINE, DEAD VOLUME

## 1. Introduction

For many years the Stirling engine has been modified and improved due to its promising theoretical cycle effectiveness. As it is known the Carnot cycle is the most efficient of all ideal thermodynamic cycles. Since the development of Stirling engine there have been many interesting and very different configurations of this engine but there is still place for new inventions. Nowadays there is new interest in Stirling engine development due to its potential in the field of renewable energy. The most of renewable energy investigations now concentrate on solar energy and those investigations have good results. However, the improvement of digital methods for computing flow process of gasses makes it possible to develop engines that consume different flammable materials with good efficiency. Engine efficiency usually ranges from about 30% to 40% with typical temperature range of 650<sup>0</sup>–800<sup>0</sup> C, and operating speed up to 4000 rpm [2].

In our case we decided to try to improve small and medium scale central heating system efficiency by addition of the Stirling engine to it. During the development process of such a system we created a new modification of the Stirling engine and now this modification will be presented to you.

## 2. Prerequisites and means for solving the problem

Difference of temperatures is a potential source of gaining energy from it and one way how to do that is by using the Stirling engine. We use the house's central heating system when it is cold outside and we try to heat up the house by burning some flammable material. So here we have the difference of temperatures and it seems logical to use the Stirling engine to improve efficiency of the heating system. It was the general idea of implementation of our modification but such engine can also be used, for example, in vehicles with inner combustion engines to use wasted heat energy from exhaust gasses. In large scale systems there exists such a solution when the heating system is equipped with the Stirling engine to improve overall efficiency but in small and medium scale systems there is a gap that needs to be filled. Therefore, our team started a project to develop such a system. In the process of developing the new device, which could convert the energy that we can obtain from the temperature difference in central heating system into electrical energy, we chose to use the Stirling engine. The task was to choose the best modification of existing versions and to improve it with regard to intensification of the amount of heat that goes through engine and in such a way to increase the overall power output of engine. Intensification is not an easy task due to geometrical limits and the necessity to provide as high temperature as possible at the hot end of engine.

## 3. Solution for the examined problem

Solution for the problem was achieved by creating a new modification of Beta type Stirling engine with provision of

a unidirectional flow of working gas. To achieve this goal the flow channels were created at the top and at the bottom of the cylinder in order to provide gas flow from volume between the upper piston and the lower piston, and between the upper piston and the cylinder head. For Stirling engine it is important to have as high working gas temperature difference as possible and in our type of engine it is provided by organizing separate unidirectional flows through the heater and the cooler. Thanks to such design the working gas takes heat energy from the cylinder head and cylinder walls quicker and smoother, providing a faster and larger pressure increase. The maximum heat exchange is achieved after top dead center and also helps to increase the power output of engine.

Flow channels at the bottom of the cylinder are connected with the top of the cylinder to provide the flow of working gas from space between two pistons back to the top of the cylinder (schematic picture of engine is presented in Figure 1). Those channels also act as working gas coolers and can be equipped with a valve that provides a unidirectional flow and separates the cooler volume from the heater volume in such a way decreasing the so called dead volume.

Dead volume is defined as the total void volume in the Stirling engine. In general, the dead volume is referred to as the volume of working fluid contained in the total dead space in the engine, including the regenerator and transfer port. In normal Stirling engine design practice, the total dead volume is approx.58% of the total volume [3]. The dead volume will decrease both the engine network and the thermal efficiency and will increase both the external heat input and output. However, a real engine must have some unavoidable dead volume. [1] In our modification by implementing a valve we can reduce the amount of dead volume by approx.50%.

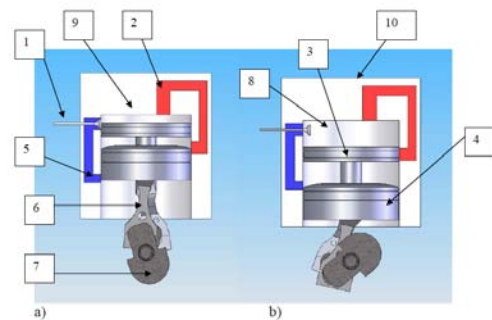


Fig. 1.

- 1 - valve
- 2 - heater
- 3 - upper piston
- 4 - lower piston
- 5 - cooler
- 6 - connecting rods
- 7 - crankshaft
- 8 - cylinder
- 10 - cylinder head
- 11 - cylinder block

The developed engine must minimally consist of a crankshaft or a crankshaft mechanism, at least one cylinder, at least one cylinder head, connecting rods of crankshaft mechanism, a heater, a cooler, at least two pistons in each cylinder, piston pins, a valve mechanism and overflow channels (Figure 1). The cylinder has two pistons in a reciprocating movement along the cylinder that are mutually offset. Offset is needed to create two variable volumes - the volume between the pistons and the volume between the upper piston and the cylinder head. The upper piston (displacer piston) and the lower piston (or the power piston) movements in cylinder are the same as in the classical Beta type Stirling engine.

#### 4. Results and discussion

In the process of development many design ideas were discussed and tested. The most part of design work has been done in the program Solidworks and flow simulation has been done in the same program's add-in Flow Simulation. During the early stage of project a few principal schemes were presented and discussed. After choosing the most promising scheme the design work on individual elements was started. In that stage the principal designs of coolers and heaters for stationary and dynamic flow were tested. The aim of those virtual experiments was to choose the most compact solution with the largest temperature difference and the smallest pressure drop.

To determine the best heat exchanger design several constructions with different channel design versions were made. Gas flow parameters were calculated in channels with the same cross-sectional areas and lengths. In input there were the same flow rates, temperature, wall temperature and pressures. Calculations for stationary flow were made for two different pressures. A few typical variations of channel flow and temperature distribution can be seen in Figure 2. The calculations were made in the add-in Flow Simulation with the same settings for all variants of calculations.

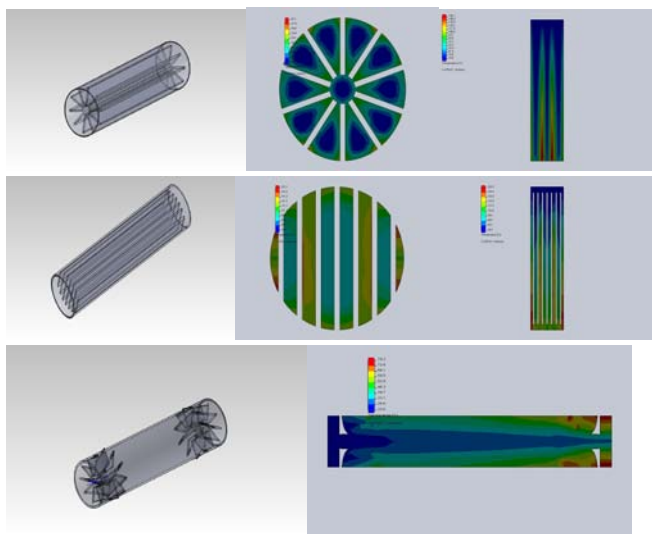


Fig. 2. Samples of some principal channel designs - longitudinal and middle cross sections of channels with temperature distributions

After the individual components calculation stage the overall construction of engine was revised and specified, so the engine got definite parameters (Fig.3).

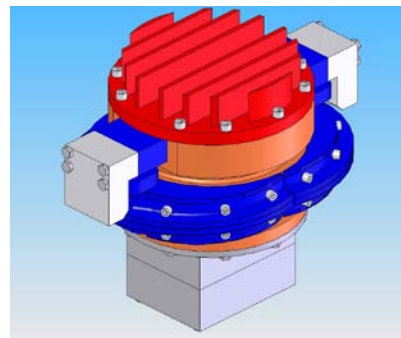


Fig. 3. General preview of the modified Stirling engine

The next stage of work was to simulate gas flow in the engine with specified geometry. The main idea of flow simulations was to reveal weak points of construction and to balance the heater and the cooler productivity. Calculations were made for a stationary and dynamic gas flow in a simplified system. The main simplification was to calculate the flow without moving parts because the program Flow Simulation unfortunately cannot solve such a task. The first calculations were stationary with the main idea to evaluate temperature differences. The next were dynamic calculations with pulsating gas flow speed, volumetric consumption and pressure input. A sample of input graphics and a sample of results are presented in Fig.4.

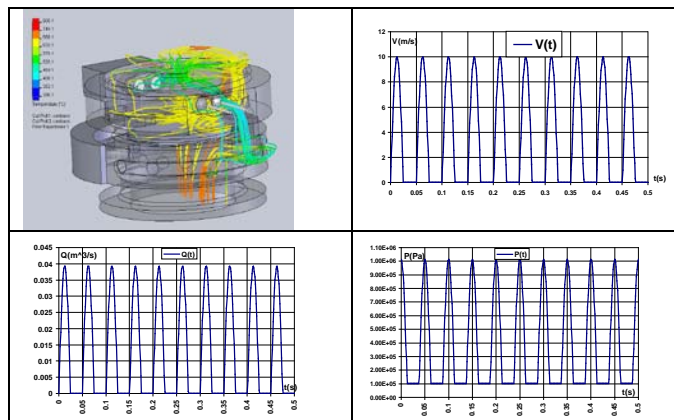


Fig. 4. A sample of flow calculation results and samples of gas flow input graphics

Calculations with regard to pulsating gas flow show better heat exchange in the heater and the cooler but at the same time there is increased pressure drop. Virtual experiments showed that there is a lot of space for improvement of channel geometry and separate investigation can be made to improve heat exchanger efficiency and dynamics for our engine construction.

Main parameters of the modified Beta type Stirling engine

Table 1

|  |                          |
|--|--------------------------|
| Working volume (volume of 1 pulsation) | 1100 cm <sup>3</sup>     |
| Hot end temperature                    | up to 800 <sup>0</sup> C |
| Cold end temperature                   | up to 60 <sup>0</sup> C  |
| Initial gas pressure                   | up to 10 at              |
| Working gas                            | air, helium, argon       |
| Pressure of cooling liquid             | up to 3 at               |
| Approximate dimensions                 | 40/50/35 cm              |
| Calculated working gas heat difference | 300-650 C                |
| Valve drive                            | electromagnetically      |

After all calculations the main engine parameters are definite, so manufacturing of the prototype has begun (Table 1). As calculations with different methods showed, our engine's maximal power output potential right now is up to 1 kW. Precise estimation of power output and engine efficiency is a difficult task due to very different effects that can be achieved by different variations of valve use.

### **5. Conclusions**

This article presents the design and principle of work of a modified Beta type Stirling engine. Some of the main design phases of the project are presented to illustrate the process of creating conceptual design for a modified Stirling engine. The presented invention improves performance of the engine at the same maximum available temperature as the existing analogues. The improvement is achieved mainly due to reduction of dead volume and by providing unidirectional flow of working gas. The dead volume can be reduced by approx.50% due to provision of valve mechanism in the engine. Owing to valve implementation it is possible to achieve different thermodynamic effects that need to be investigated in subsequent projects. The target power output estimation of a prototype that will be built on the basis of the presented modified Stirling engine is 1 kW. At the moment complete modulation of all thermodynamic processes of gasses in Stirling engine is hard because new software products are imperfect. Therefore, it is very important to make natural experiments, which will reveal the true potential of new modification.

### **6. References**

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