MODEL OF STIRLING ENGINE

Ing. Jan MACHÁČEK, Doctoral Degree Programme (1)
Dept. of Electrical Power Engineering, FEEC, BUT
E-mail: xmacha08@stud.feec.vutbr.cz

Supervised by: Ing. Jan Gregor, CSc.

ABSTRACT

The goal of this paper is to describe basic principles and practical use of Stirling engine, an external combustion engine that converts heat into useable mechanical energy. Due to the increased awareness of internal combustion engines' impact on environment there is a renewed demand for cleaner energy systems. The Stirling cycle engine has several potential advantages over the traditional internal combustion engine including low noise, low pollution and better fuel versatility. In this article, measurements of operating characteristics and analysis of its performance are also presented.

1 INTRODUCTION

The Stirling engine belongs among the simplest form of engine and has a long history. The engine, then called the economizer, was first developed and patented by Rev. Robert Stirling in Edinburgh, Scotland in 1816. At that time, steam engines had a rather low efficiency and were quite unsafe. Boilers exploded often, and the high pressure steam that was released had scalding effects. The Stirling hot-air engine promised to overcome both problems. However, the Stirling engine could never live up to expectations. Meanwhile the steam turbine improved more and more to today's level of efficiency and internal combustion engines, i.e. Otto and Diesel engines, prevailed for the use in cars. Stirling engines could not compete and almost vanished from the scene.

A revival in the development of the Stirling engine was again started in the 1930's. The Stirling engine always took a back seat to more popular engine designs such as the steam engine and the internal combustion engine. But today as people have forecasted the eventual exhaustion of fossil fuel sources, the Stirling engine concept has regained the interest of many developers. The engine can run on a variety of fuel sources and has a work output far closer to the theoretical ideal efficiency than most engines.

The mechanical configurations of Stirling engines are generally divided into three groups known as the α, β, and γ arrangements. Alpha engines have two pistons in separate cylinders which are connected in series by a heater, regenerator and cooler. Both Beta and Gamma engines use displacer-piston arrangements.

2 PRINCIPLE OF FUNCTION

The Stirling cycle involves a series of events that change the pressure of the gas inside the engine, causing it to do work. The key principle of a Stirling engine is that a fixed amount of a gas is sealed inside the engine. Although, the basic fundamentals of Stirling system are similar to a petrol motor, there are some important differences between them:

There is a hermetically sealed gas in the inside working capacity of the motor. This gas does not exchange with its surroundings (cycle is closed) unlike the petrol motor. The gas does not change in state.

The inside working capacity of the motor is in the form of a heater, cooler, capacity of the heat exchanger, stroke capacity of the pistons and regenerator. There are no barriers and valves between the parts in the total working capacity of the motor.

The gas is transferred to the heater where it is heated by hot sides. The cooling uses the same principle as the heating but it is made in the cooler. The gas is transferred by the displacer from the heater to the cooler. The displacer is driven by the crank shaft. During its movement the total working capacity of the motor is not changed (vide Figure 1). The motor has a power piston, connected to the crank shaft. The power piston is driven by compression and expansion. The power piston drops behind the displacer. During every turn of the crank there is a cycle of compression, heating, expansion and cooling.

The important part of the motor is the regenerator. It is located between the heater and cooler and the gas must go through it. When the gas goes to the cooler, the regenerator takes away its heat. When the gas goes to the heater the heat energy is given back to it. Thus, the heat energy is not lost. The regenerator increases efficiency of the Stirling engine.

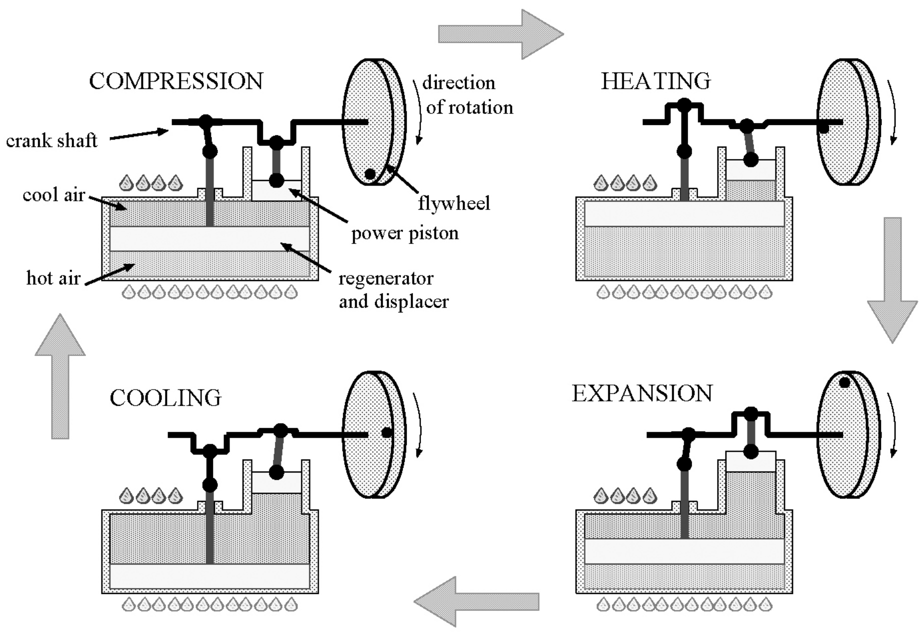

Figure 1: Principle of Stirling cycle.

2.1 PHASES OF CYCLE

The idealized Stirling cycle is a thermodynamic cycle consisting of isotherms and isochors depicted in Figures 1 and 2.

The first phase, called *isothermal compression*, includes compression of the gas by working piston (line 1-2 at p-V diagram). The gas releases the heat to the cooling water so that its temperature remains nearly constant. This phase describes formula (1):

$$W_{1-2t} = -\int_{1}^{2} v\,dp = \int_{1}^{2} p\,dv \tag{1}$$

During second phase (Figure 2, T-s diagram, abscissa 2-3), the cool gas is streaming upwards through the regenerator, where it receives the energy, i.e. the heat. The temperature T_1 increases to the temperature T_2 - *isochoric heating*.

$$W_{2-3t} = v(p_2 - p_3) \tag{2}$$

In *isothermal expansion* (third phase), most of the working gas is in the upper hot zone. The working piston moves downward due to the expansion of the gas. The heat supplied is thus (mostly) transferred into work (temperature T_2 is constant).

$$W_{3-4} = W_{3-4t} \tag{3}$$

Isochoric cooling, phase 4 of the cycle, is characterized by decrease of temperature T_2 to temperature T_1. The piston is moving upwards and the working gas streams into the lower cold part of the engine (total volume of gas is constant). While flowing through the regenerator, the gas releases heat to it.

$$W_{4-1t} = v(p_4 - p_1) \tag{4}$$

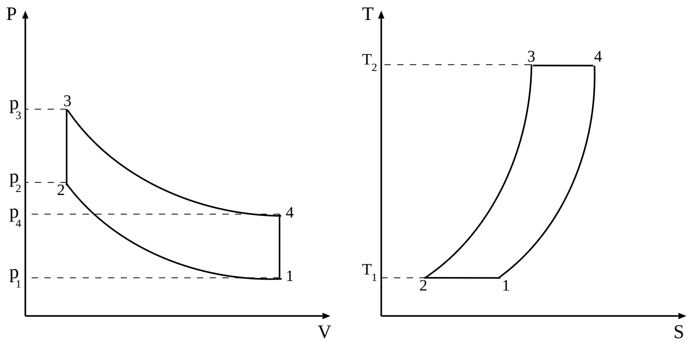

Figure 2: p-V and T-s diagrams.

If the heat released during period 2-3 is equal to the heat used in stage 4-1, then the heat exchange between the gas in the system and environment is characterized by temperatures T_2 and T_1.

$$\mu = \frac{T_2 - T_1}{T_2} \tag{5}$$

3 MODEL OF STIRLING ENGINE

The model of the Stirling engine constructed by the Department of Electrical Power Engineering (Figures 3 and 4) is combination of Beta and Gamma type. The displacer, having also a function of regenerator, and the power piston of engine lie in one axe. This model has a low load (watt's unit) and serves for experimental research and educational objects.

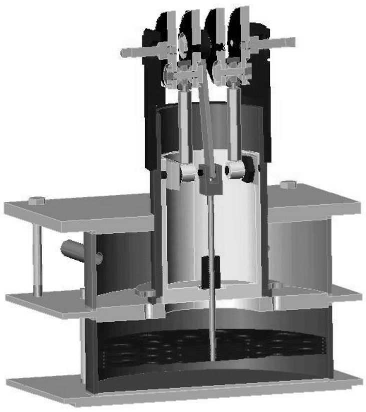

Figure 3: Cross-section of the model.

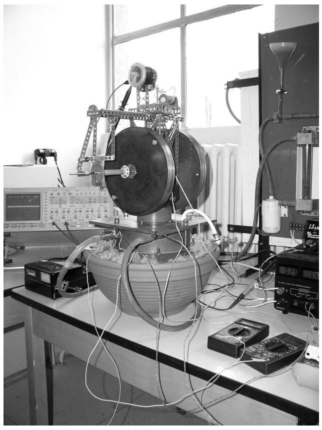

Figure 4: Picture of laboratory model.

4 OPERATING CHARACTERISTICS

Mentioned model of Stirling engine is suitable for assessment of various parameters and characteristics of the motor, including p-V diagram, engine moment and engine load. The relations between varied power drain and engine moment or load are shown in Figures 5 and 6, respectively. Based on depicted characteristics of the Stirling model, it is possible to obtain important data characterizing the system, e.g. the optimum load of the motor for delivered power drain, the optimum revs etc.

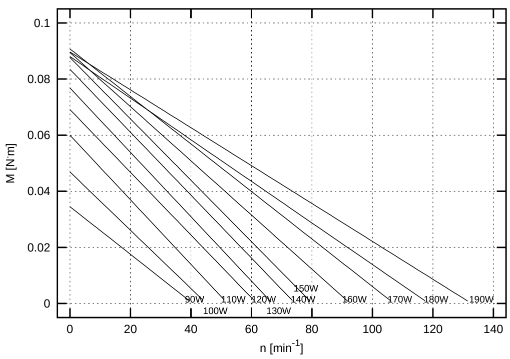

Figure 5: Moment's characteristics.

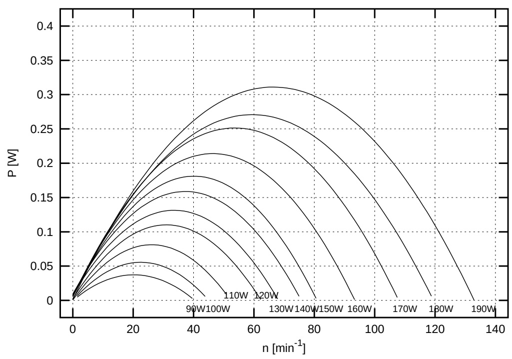

Figure 6: Load's characteristics.

The actual thermodynamic cycle of the Stirling engine differs slightly from the idealized Stirling cycle; see Figure 7 for a comparison of the idealized and real cycle. Main reasons why the measured p-V diagram varies from the ideal one include the physical limitations of engine design, heat losses to the environment, imperfect isothermal conditions etc. Analysis of Stirling engine and its properties provides new ideas to develop efficiently working system with improved features (i.e. engine load and moment) and technical innovations equivalent to current technical requirements.

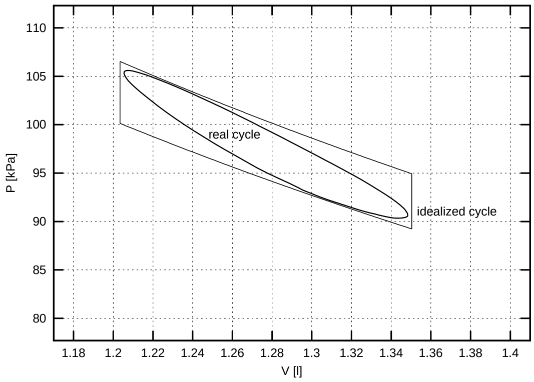

Figure 7: The real and ideal p-V diagrams.

5 CONCLUSIONS

This article presents a general description of function and practical use of the Stirling cycle engine. It also describes a functional model of the Stirling engine constructed by the Department of Electrical Power Engineering, FEEC, Brno University of Technology. Despite the low load of the described model, it provides a sufficient demonstration to graphically illustrate the procedures, methods of assessment and measurements of the engine operating parameters. Based on measured and analysed characteristics of the Stirling model, it is possible to exactly calculate the properties of the system, including efficiency, moment and load of the motor by its power drain and revs.

Stirling engines produce almost no pollution. With a regenerator, the Stirling cycle approaches ideal efficiency and thus leads to better fuel economy than current engines. The engine is simple, quiet, and can utilize many types of fuels. The Stirling engines will someday become more popular as exhaust emissions regulations continue to be more and more restrictive, and oil prices rise to a point where we will be forced to use low emission engines.

REFERENCES

[1] Haywood, R. W. *Analysis of Engineering cycle.* Pergamon Press, fourth edition, 1991.

[2] Kaleta, R., Gregor, J. *Aplikace Stirlinova motoru v systémech konverze eneregie.* Liberec : Sborník konference aplikovaná mechanika. 2000. 143 s.
ISBN 80-7083-388-2

[3] Kleczek, J. *Sluneční energie - úvod do helioenergetiky.* 1. vyd. Praha : Nakladatelství tech. lit. 1981. 192 s. Edice Polytechnická knihovna ; řada 1 MDT 523.72:620.9.