

ENCIT-2018- 0743 MANUFACTURING AND ANALYSIS OF AN ALPHA TYPE STIRLING ENGINE PROTOTYPE

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Abstract. *The use of polluting and non-renewable energy sources has become a global problem. There is a prominent interest of multinationals and government companies in researching and discovering new energy resources that reduce environmental aggression, compare fossil fuel efficiency and maintain the profits generated by energy production. Stirling engines come up as an alternative to generate clean and renewable energy, from the most diverse sources of heat. The principle of these engines is based on the external combustion of fluids contained in pistons, which are submitted to temperature changes, volume and pressure during an operating cycle. In this project, the Stirling type alpha engine will be used to produce mechanical work in order to obtain analyzes on the consumption, efficiency of the use of different fuels, the effective power generated, the advantages and disadvantages of the application of these mechanisms experimentally and according to the data collection, the development of these machines in real size would emerge as a fundamental trend for the dynamics of renewable energy generation.*

Keywords: *energy production, Stirling engines, external combustion, efficiency*

1. INTRODUCTION

With the advent of the scientific-informational technical means, it was verified the need for effective forms of energy production that would support the current industrial system. Faced with this, in response to the scarcity and effects of fossil fuels, renewable energy sources emerge as an alternative solution for the stable establishment of the energy matrix.

The development of clean energy forms and the technological improvement have allowed its use in several industrial scenarios accelerating the viability of a sustainable use of the environmental resources, in this way, outside the interest in the search for the development of new technologies that allow the generation of this conception of sustainable and economic energy. In this context, the application possibilities offered by the Stirling-type engine, due to its intense accessibility to the combustion of fuels, characterize the external combustion engines, where all research work related to them becomes of paramount importance for a greater development of the technology, aiming at increasing performance, especially with the use of previously discarded energy sources.

Stirling engines are special thermal machines, defined as a cylinder-piston mechanical arrangement and a source of heat external to the cylinder. In terms of thermal efficiency, they are able to overcome that of other systems, such as those of the Rankine cycle, which can reach the efficiency of Carnot, proving to be a viable, economical and energetic alternative in relation to its diverse applications such as: replacement of photovoltaic solar units [1].

These external combustion engines work by the expansion of a gas when heated, followed by compression in which is cooled. The gas is in a fixed amount which is transferred back and forth between the cold and hot source. A movable piston - or more - is responsible for directing the gas between these two extremes.

With regard to the applications, it can be used to obtain mechanical work or kinetic energy with the purpose of converting it into electrical energy, in addition to being able to use thermal sources that would be wasted by another process [2]. Because they are quiet, greener and more efficient, they are also designed for refrigeration systems

2. STIRLING CYCLE ENGINES

The engines of the Stirling cycle are thermal machines discovered in 1816 by Robert Stirling, in order to obtain a mechanism equivalent to the steam engine, but with a lower degree of danger.

The operating cycle of this engine is based on the expansion and compression of a gas, called the operating gas, it is constrained to move cyclically from a cold source where it is compressed and a hot source where the expansion process will take place the driving force is based on the temperature gradient imposed between the sources.

Theoretically, the efficiency achieved by the Stirling engine is higher than any other thermal engine, able to reach an approximate value of 45%. However some practical constraints reduce the efficiency of these machines, such as limits on heat transfer in relation to convection, fluid viscosity, friction between parts and the presence or absence of regenerator.

2.1 Stirling Engines's Variety

Stirling engines, according to their architecture, are classified into three types: beta, gamma and alpha.

In the beta configuration (Fig.1), the pistons are aligned in a single cylinder. By overlapping each movement of both pistons, a higher engine compression ratio is obtained. However, the displacement and working piston rods are aligned, which makes the synchronization mechanism complex.

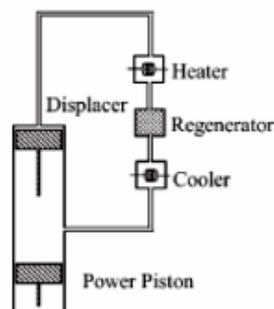


Figure 1. Schematic configuration of the beta type. [3]

The gamma variant shows the constitution of two independent cylinders, one hot and one cold (Fig. 2). The hot one moves the working fluid between the ends, suspended by a sliding rod through the center of the hot cylinder, which completely surrounds it. The working piston is separated from the hot cylinder and is responsible for the work of the engine, which may be the work of compression and expansion.

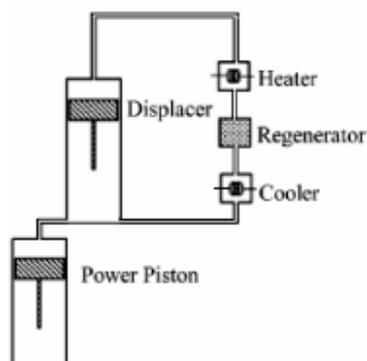


Figure 2. Schematic configuration of gamma type.[3]

Those denominated of the alpha type consists of two independent cylinders connected by a hose in which the regenerator is located, responsible for the management of the gas heat between chambers, in each cylinder there is a movable piston with 90 degrees of lag between sources, where one of them is heated by one heat source and the other is maintained at room temperature or water cooled, the space delimited by the distance between the pistons allows the air to circulate, performing the compression and expansion steps determining the operation of the mechanism. Fig. 3

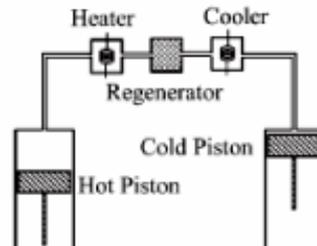


Figure 3. Schematic configuration of the alpha type arrangement.[3]

The ideal Stirling cycle combines four processes, two isothermal processes and two constant volume heat exchange processes. According to the pressure and temperature diagram in figure 4, the work is done in or produced by the cycle only during constant temperature processes, however, heat must be transferred during all four processes [4].

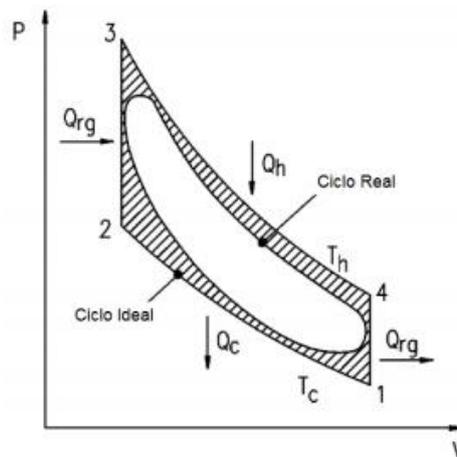


Figure 4. Ideal cycle against the real. [3]

The four stages of the Stirling cycle can be defined, such as:

1-2. Isothermal compression: At this stage the main piston fluid is compressed and flows into the cooling piston, where it is compressed. In this case, the main piston fluid undergoes a negative work, but is lower than the work done in the first phase, occurring at constant temperature.

2-3. Isocoric heating: At this moment, the pistons maintain the previous position, that is, at constant volume. However, there is a heating of the internal fluid.

3-4. Isothermal expansion: At this stage a positive volume variation occurs, i.e., the fluid expands in the main piston while the cooling piston both compresses the constant temperature. It is considered as the phase in which the system performs positive mechanical work.

4-1. Isocoric cooling: the cycle is completed at this stage. The positioning of the pistons is fixed, and the expansion previously occurred in the cooling piston, causing a decrease in fluid temperature. Then, the cycle resumes the volumetric expansion phase.

In practice, the processes that occur do not follow the ideal cycle. There are fundamental factors that hinder the ideal functioning of the machine, they are: the reciprocating movement of the pistons, the imperfect regeneration and the dead volume.

Dead volume is the major cause of engine inefficiency, and is due to the full use of the gas volume during operation, i.e., part of the gas remains stationary in the engine chambers. Regeneration involves heat recycling within the cycle: During the cooling the newly heated fluid loses heat to equilibrate with the cold source, part of that fluid is

transported by the regenerator to the heating part, thus the fluid you will need less power from the source and there is less energy expenditure [5]. These factors end up changing (rounding off) the pressure-volume diagram of the system, expressed by figure 4.

3. METHODOLOGY

From the tests carried out on the prototype, it was possible to obtain data in order to verify and compare some work variables, which were consumption, service temperature, voltage and power. Thus, a series of procedures was adopted providing the data collection. For each parameter collected, the following techniques and equipment were used.

In order to obtain the measurement of the fuel consumption, the DIGIMED model DG-15WT digital scale was used. In order to evaluate the variation of the mass in real time, taking an initial mass quantity and, after a stipulated fixed interval of 10 minutes, using a 25 ml capacity flat bottom volumetric flask and the tests were applied adopting as precursor agents hydrated and anhydrous ethanol. The balance specifications, found in the manufacturer's manual, are listed in table 01 below:

Table 1. DIGIMED DG-15WT balance specifications used in the consumption analysis.

Parameters	Specifications
Manufacturer	DIGIMED
Model	DG-15WT
Capacity (kg)	15
Resolution	0,1g
Reproducibility	± 0,2g
Linearity	± 0,2 g
Digital Output	RS232
Feeding (Vca)	90 a 240

In order to acquire specific variables in the tests, the data acquisition unit CONTEMP A202 was manipulated to record and monitor the analog variables and with the aid of the D-501 USB converter the analog signal was transformed into a digital signal, which was reproduced through Azeotech's DAQ FACTORY software. This was applied to capture the signals emitted by the thermocouples, allowing them to be read on the computer. Also, with the aid of a protoboard plate containing three resistors (220Ω each) associated in series with the function of simulating loads to the system, where it was possible to obtain the measured voltage parameters, respectively, without load, one load, two loads and three loads.

In the course of operation, due the stability achieved by the prototype, a series of measurements were used with a MITUTOYO PH-200LC tachometer to verify the rotation of the flywheel. All of the cited parameters were supported for all fuels tested in order to evaluate the efficiency, generation and consumption results.

4. RESULTS

Several advantages are found in a Stirling engine, among them stand out:

- Sustainability proposal: Unlike internal combustion engines, in Stirling engines, combustion is continuous, thus allowing greater efficiency, due to the more complete and efficient use of the fuel.
- Feed Variability: Stirling cycle engines can use almost all known energy sources, since they are of external combustion, among the main ones are: ethanol, methanol, natural gas, diesel, biogas, solar energy and even geothermal heat.
- Quiet operation: The fact that it has no valves or many moving parts, the noise and vibration levels are lower than the conventional ones.
- Low maintenance: The combustion products do not come into direct contact with the moving parts of the engine and, therefore, there is no contamination of the lubricant. In Stirling engines, unlike internal combustion engines, temperatures are lower and the engine walls can be cooled, which allows even the use of water as a lubricant in place of oils.
- Diversity of adaptation: Since the Stirling engine consists of simple elements, these can be arranged in different ways, thus allowing a greater adaptation to different physical spaces.

The disadvantages are highlighted with:

- High cost: The Stirling engine is still more expensive than a diesel engine of the same power, for example. These price differences arise from the manufacture and production of its elements which, despite having a simple arrangement, specific materials are necessary for its effective operation.

- Quality of sealing: Stirling engines require good sealing of the chambers containing the working gas to avoid contamination of the lubricant. The efficiency of the engine is usually higher at high pressures, depending on the gas used, but the higher the working pressure, the greater the difficulty in sealing the engine.

The final values presented are able to determine the efficiency of the system from the direct relation between the thermal power (or heat flow) and the effective power at the output of the electric generator. It is worth mentioning that this method of calculation does not take into account the losses associated with the steering and steering movement during the heating of the expansion chamber of the Stirling engine [6].

Thermal energy is defined as being a transmission of thermal energy from one energy body to another less energetic, which can be driven by three modes of propagation: conduction, convection and radiation.

The thermal power of a given fuel is determined by the equation:

$$Q = \dot{m} * PCI$$

Q – Thermal Power (W);

\dot{m} – Mass Flow (kg/s);

PCI – Inferior calorific power (kJ/kg);

The inferior calorific power is defined as the amount of heat that can produce 1kg of fuel when it burns in excess of air and the products of combustion are cooled to the boiling point of the water, thus preventing the water contained in the combustion is condensed [7].

Table 2. Specifications of the calorific power of some fuels. (ANS/SPD).

Fuel	Inferior calorific power (kcal/kg)
anhydrous ethanol	6750
hydrous ethanol	6300
Biodiesel (B100)	9000
LPG	11100
Gasoline Aviation	10600
Illuminating Kerosene	10400

Thermal efficiency consists of the portion of power consumed by a system that is converted into work, and is given by:

$$\varepsilon = \frac{Pe}{Q}$$

ε - Thermal efficiency;

Q - Thermal power hot source;

Pe - Effective power at generator output;

Table 3. Data for the calculation of Thermal Efficiency using Anhydrous Ethanol.

Resistive load (Ω)	Mass flow (kg/s)	Thermal power (kW)	Effective Power (Electric)(W)	Thermal Efficiency
220	0,0005647	15,9483	0,041456	0,00025994
440	0,0006995	19,7553	0,02046	0,00010354
660	0,0006409	16,8935	0,01056	0,00006251

Table 4. Data for the calculation of Thermal Efficiency using Hydrous Ethanol.

Resistive load (Ω)	Mass flow (kg/s)	Thermal power (kW)	Effective Power (Electric)(W)	Thermal Efficiency
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220	0,0006735	17,7396	0,04256	0,0002399
440	0,0006229	16,4217	0,02241	0,0001365
660	0,000704242	18,5567	0,01080	0,0000582

The Figure 5 shows the flame temperature, which reached around 750 ° C.

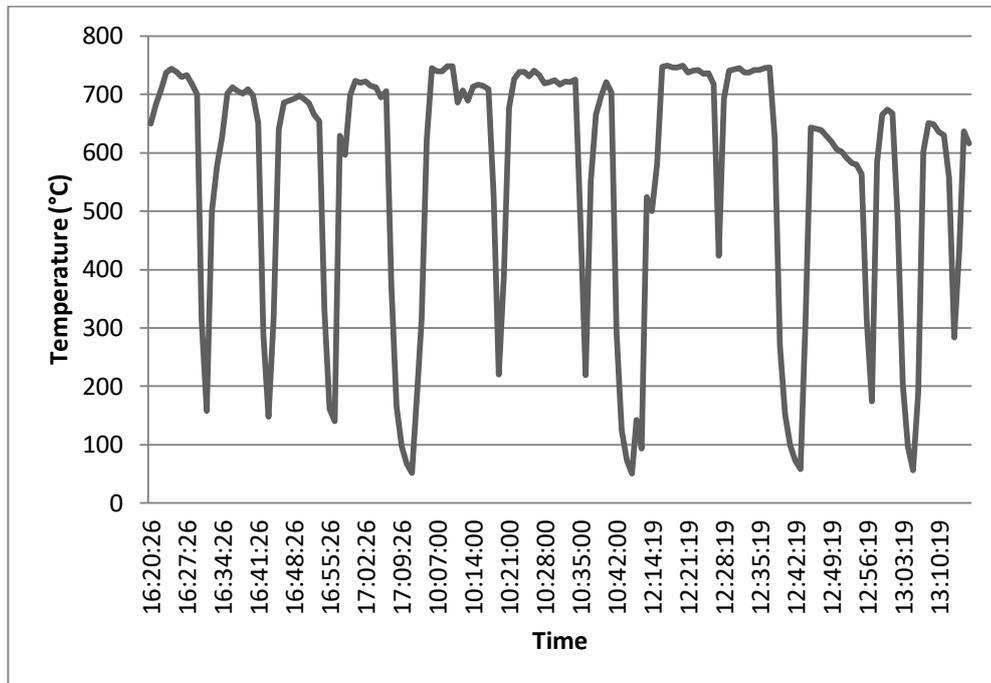


Figure 5. Flame Temperature versus Time.

The Figure 6 shows the voltage generated by each load added in the motor, ranging from 0 V, to no load and to about 4.5 V for a resistance of 660 Ω.

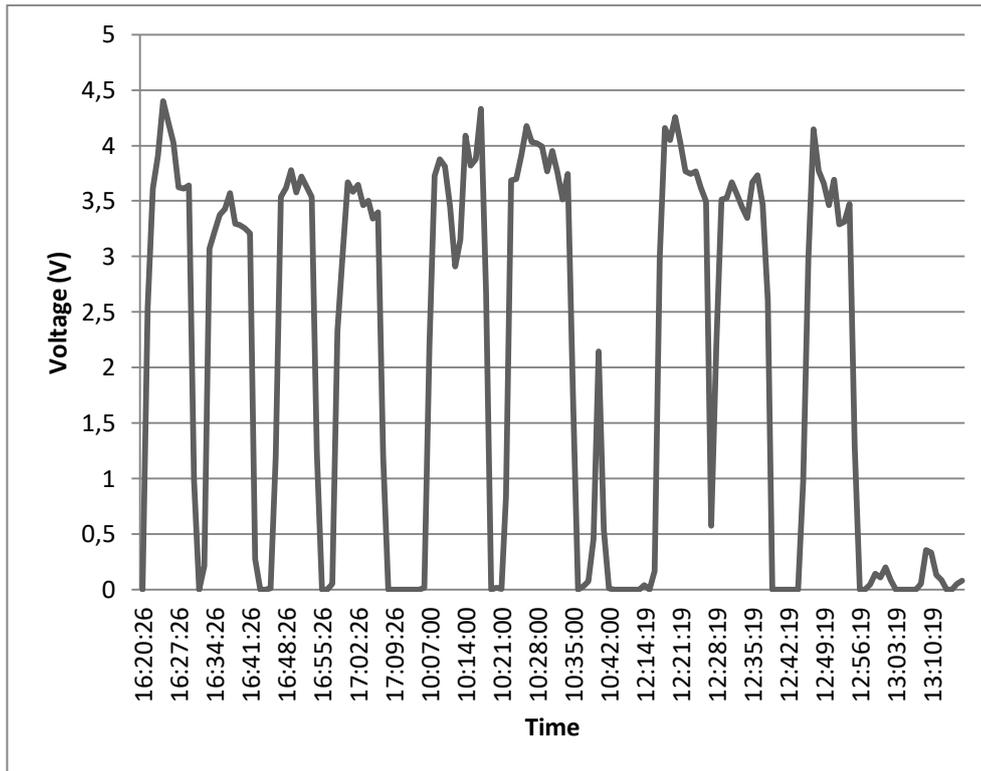


Figure 6. Voltage generated over time.

The Figure 7 shows the schematic drawing of the motor used for data collection.

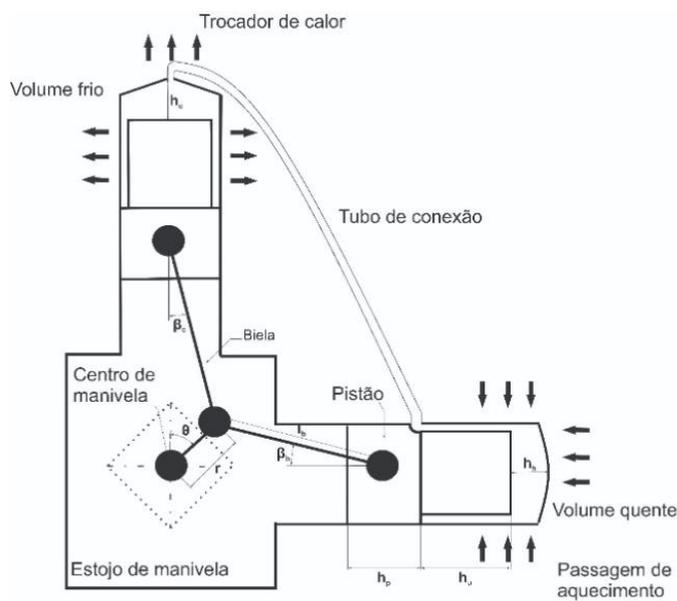


Figure 7. Schematic drawing of α -type Stirling engine prototype.

5. CONCLUSIONS

Note that the Stirling engine proves to be an alternative tool in many applications of harnessing a power source, because depending on its size, you can, for example, charge a battery of a stationary engine or light some lamps, demonstrating its diversification of fuel use and its applicability. In this prototype, the construction took place in a

simple way, but the project requires certain precautions regarding the friction between moving parts, since its generation is small, this factor becomes relevant as to the performance of this thermal machine.

The prototype aims at the analysis on a smaller scale, monitoring consumption and generation data for extrapolation purposes to a larger engine, increasing its conditions of use and, based on the results, seek the improvement of this engine for its cost-benefit and expanding the idea of resorting to sustainable solutions in the energy sector.

6. ACKNOWLEDGEMENTS

The authors thank Prof. Dr. Hendrick Maxil Zárata Rocha for all support and collaboration arranged during the process of formulation and elaboration of the project, as well as the help provided by the Motors Laboratory, which is part of the EBMA Group - Biomass Energy and Environment, Federal University of Pará. And also, to the relatives and friends for the support and understanding.

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