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Design and Thermodynamics performance evaluation of a new Stirling engine prototype

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Abstract— in this study we will make a Thermodynamics analysis of a Stirling engine to evaluate the performance based on thermodynamic balance, looking for a motor cycle high performance, multi-source energy and less pollution resulted in the revision of the Stirling cycle. Many prototype engines were designed, but their performance remains relatively small compared with other kinds of combustion engines. In order to enhance their performance and analyze their operations, a numerical simulation model taking into account the heat losses has been developed and used in this document. To optimize engine performance, a model for predicting of energy was created for an innovative solar concentrator system connected to Stirling engine. The performance forecasting models have been implemented in the EES Software taking into account the location and long-term performance of such system.

Index Terms— Thermodynamics, Stirling engine, optimal design

Introduction

Also known as hot-air engine, the Stirling engine is an external power engine. The primary fluid is a gas subjected to a thermodynamic cycle which converts heat energy into mechanical energy. The basic principle of operation of a Stirling engine lies in the heating of a cylinder which causes the expansion of a piston so as to move a gas. The cooling reduces the volume of gas thus moving the piston in the opposite direction [1]. There are three types of Stirling engines.

The urgently need to preserve from fossil fuels and use of renewable energies has leads to the use of Stirling engines, which have excellent theoretical productivity equivalent to that of Carnot. They can utilize any source of power (combustion energy, solar energy) and are cleaner than conventional engines.

The solar concentrator presented in this paper was designed and fabricated by IDCmem. This innovative system can be used in several interesting applications like seawater desalination, domestic water heating and electrical power generation by the Stirling engine.

I. DESCRIPTION OF THE BI-ENERGY SOLAR CONCENTRATOR

The system module is 2,1 meters long by 2,1 meters wide. It consists of an autonomous and modular micro-concentrator which makes it possible to concentrate the solar radiation with automatic tracking of the sun.

The dual energy solar tracker consists of both photo-voltaic panels for electricity production and a multitude of mirrors that reflect solar rays on a Stirling engine located inside the collector (Figure 1).

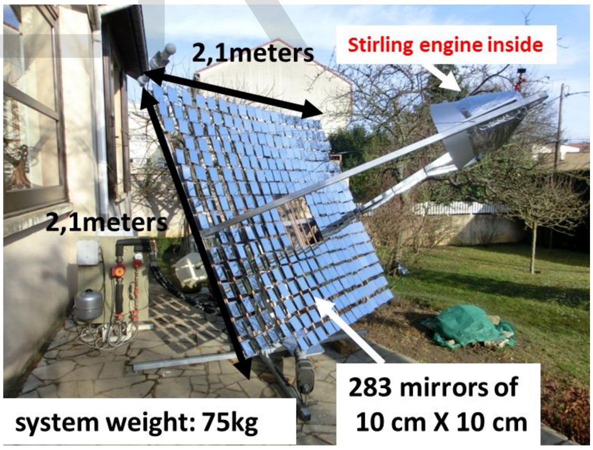

Figure 1: The Bi-energy solar concentrator

The basic configuration is equipped with 283 mirrors 10x10 cm (2.83 m²). The floor space is 2,1x2.1 m. The system power can be modified by choosing the number of mirrors (mirrors up to 900 (9 m²) on the basic mechanical structure). The orientation of each mirror enables to define the position of the focusing point

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(possibility to adapt one or more heat exchangers of various shapes).

A plumber or heating engineer will easily be able to assemble and carry out maintenance of the system (Figure 2).

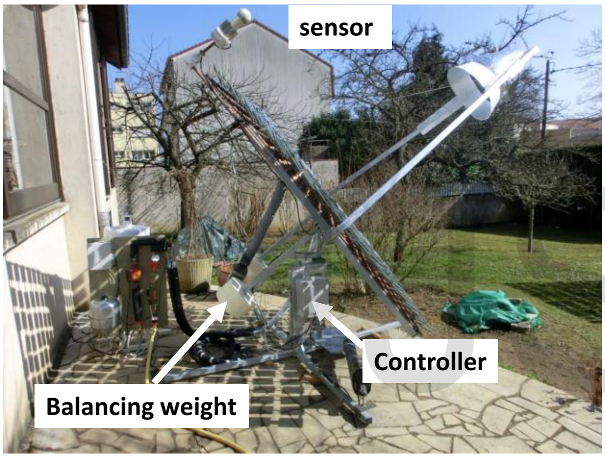

Figure 2: Concentrator mechanism fabricated with hot galvanized steel

The mobility of the system, the weight and the small space needed to install it will enable this system to be used in multiples situations, gardens, flat-roofed homes, terraces…

II. OPERATING PRINCIPLE

The Solar Stirling system shown in Figure 3 generates electricity by using focused solar thermal energy to conduct a Stirling engine. The system utilizes linear mirrors with a dual axis tracking system to concentrate the solar radiation onto a receptor in the Stirling engine. The receptor consists of a heat exchanger for transferring the solar energy absorbed by the working fluid, typically a hydrogen atom [2]. The Stirling engine then converts the heat absorbed into mechanical energy by expansion of the gas in a cylinder-piston in a manner similar to a gasoline or diesel motor. The linear movement is converted into a rotary movement to an electric generator to generate electricity.

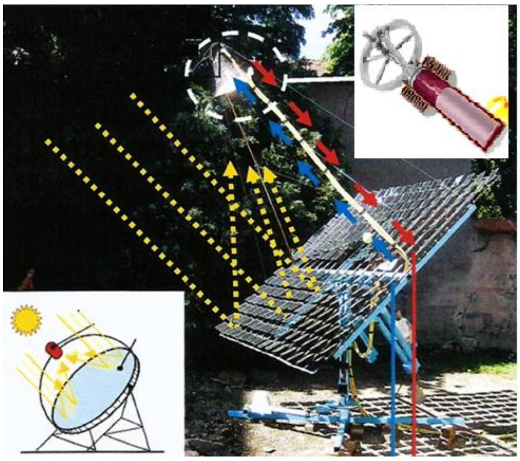

Figure 3: Solar Stirling system

a. Basic principle

The Stirling engine works through the pistons and a working gas; it follows thermodynamics cycle. The hot source of the Stirling engine is located outside the cylinder [3]; the heat energy from the heat source is indirectly transmitted to the working gas. This engine consists of a piston and a displacer gas forming a synchronous mechanism [4]. The stages of the Stirling engine thermodynamic cycle are: (see Figure 4):

Step 1: isothermal compression
During the compression step, the displacer is at the hot source to the top dead center. The piston moves by compressing the gas. The gas exchanges heat with the cold source and the transformation is isothermal.

Step 2: isochoric heating of the gas
The displacer moves to the heat sink, gas joined the hot source and its temperature increases. The piston approaches the top dead center and move slowly (see Figure 4). The transformation is isochoric.

Step 3: isothermal expansion
The displacer is at the cold source, at bottom dead center; the gas expands and pushes the piston that generates mechanical work.

Step 4: isochoric cooling
The displacer moves to the hot spring, gas joined the cold source. The piston is at bottom dead center, the volume is constant.

The Stirling engine follows the theoretical thermodynamic cycle following in the plane (P, V).

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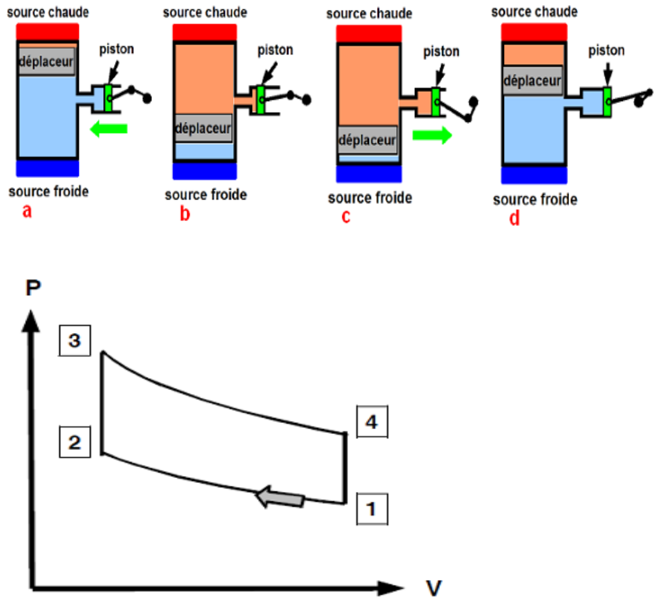


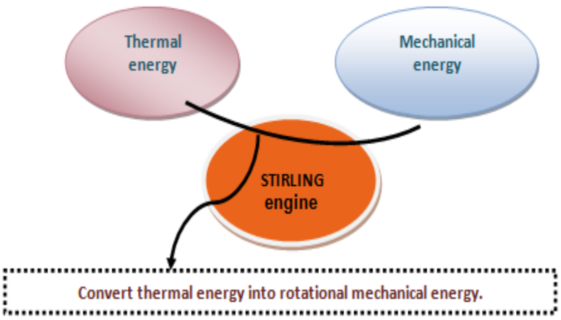
Figure 4: Theoretical cycle of the Stirling engine

1 → 2 corresponds to the isothermal compression in the cold temperature T1
2 → 3 corresponds to isochoric heating of the gas volume V2
3 → 4 is the isothermal expansion to the hot temperature T3
4 → 1 is the isochoric cooling volume V4

III. Technological Study of the Stirling Engine

This part concerns the technological analysis of the Stirling engine. We start this study by establishing the diagram below.

a. Bull chart diagram



In designing our Stirling engine we started to look for designs already done for inspiration. In our research, we were limited to not very large Stirling engines: length of the cylinder between 15 and 16 cm diameter and about 80mm. We found several designs in particular two were very interesting.

The crank rod system is a plane mechanism. In the plane (x, y) of the following scheme can be represented full-scale displacement of each piece. The geometry depends on:

- Radius R = OA crank
- Length L = AB of the connecting rod
- Distance between the point O and point B. moving right

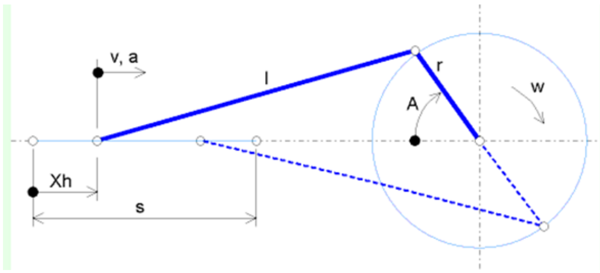


Figure 5: crank rod system

It defines the relationship: $\lambda = \frac{r}{l}$

We obtain:
Movement of the piston:

$$X_{hf} = r(1-\cos A) \pm \frac{r^2}{2l}\sin^2 A$$

Piston speed:

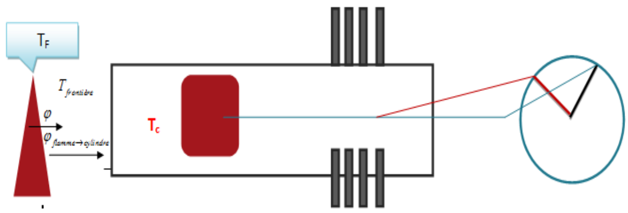
$$V_{hf} = rw\sin A(1 \pm \frac{r}{l}\cos A)$$

The acceleration of the piston:

$$a_{hf} = rw^2(\cos A \pm \frac{r}{l}\cos 2A)$$

b. calculation of hot temperature

To size the engine, it is necessary to estimate the hot temperature.



To estimate the hot temperature, the flame is considered to be a source modeled by a circular section.

The flow generated by the source is estimated to

$$\varphi = 35kW / m^2$$

And the flame temperature:

$$T_{flamme} = 2750K$$

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So $\varphi = h(T_{flamme} - T_{frontière})$, Consequently:

$$\boxed{T_{frontière} = 1350K}$$

The flow exchanged between the flame and the cylinder section:

$$\varphi_{flamme \to cylindre} = f_{flamme \to cylindre} S\varphi$$

With $f_{flamme \to cylindre}$ a form factor which is fixed at 0.5 from the charts.

As for the flow transmitted to the air inside the cylinder

$$\varphi_{transmis} = (1-\alpha)\frac{\lambda S}{e}(T_{frontière} - T_c)$$

With $\alpha = 0.15$ the absorption coefficient of aluminum which is determined from a table.

With the conservation of flux

$$\varphi_{flamme \to cylindre} = \varphi_{transmis}$$

The air temperature is determined within

$$T_c = T_{frontière} - \frac{f_{flamme \to cylindre}\varphi e}{(1-\alpha)\lambda}$$

Then:

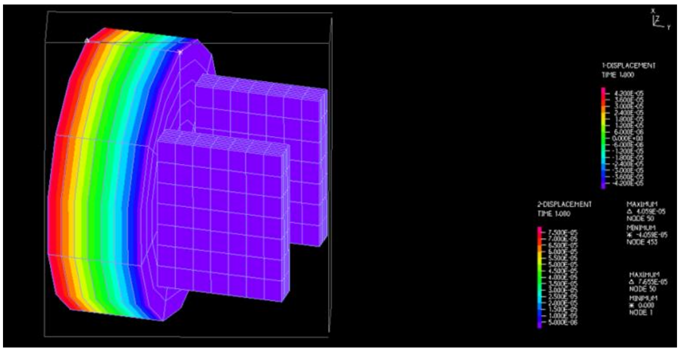
$$\boxed{T_c = 835K}$$

c. Study design

This part concerns the study of deformation occurring in the cylinder, connecting rod and piston. These have been considered the most stressed. This study was made through ADINA structural analysis software.

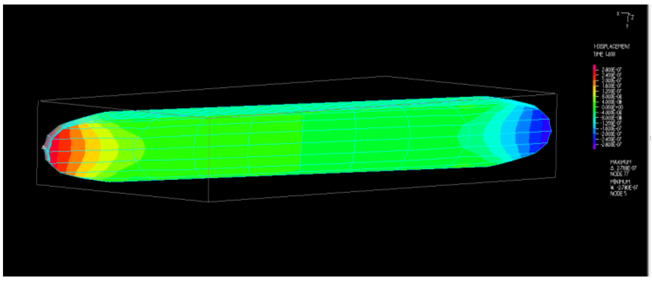
- **Study of the piston**

The pressure applied to the face of the piston results in deformations in the movement of the piston axis. The maximum displacement is in the order of 4 * 105 mm.



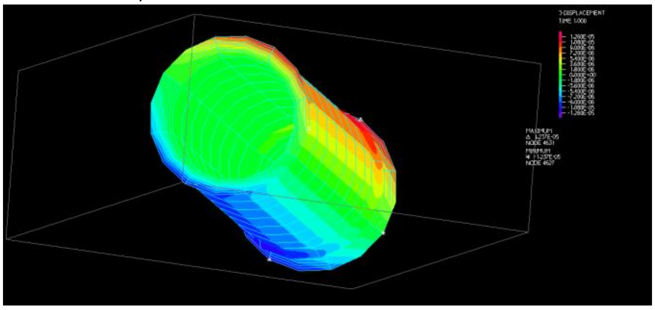
- **Study of the rod**

Because the movement of the crank-rod system, the ball experiences tensile forces in both ends. This displacement is of the order of 3 * 107 mm.



- **Study the cylinder**

The engine cylinder which receives the internal pressure of the order of 4 bars. This pressure causes the expansion of the cylinder. Our study showed that this expansion up to a magnitude of 2 * 105mm,



d. Thermodynamic study

A model was developed in Engineering Equation Solver (EES) to evaluate the thermodynamic performance by establishing the equation and energy balance with the change many of the different input parameters.

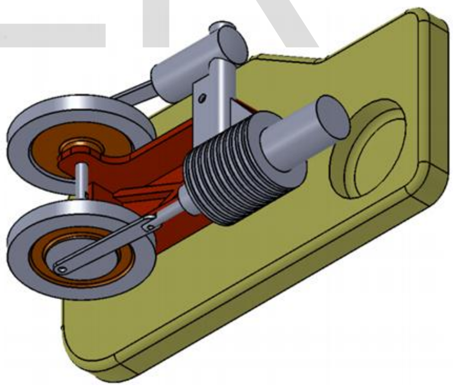


Figure 6: Stirling engine prototype

Here is the program interface on the EES software with input parameters that can vary and output parameters

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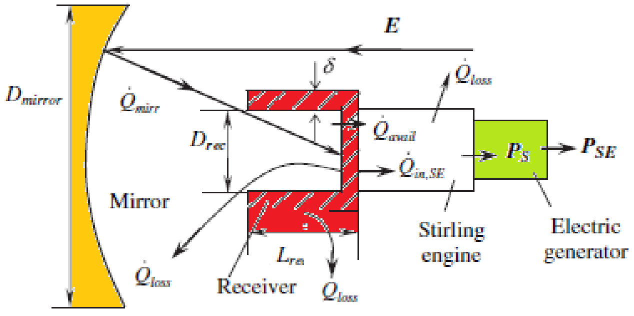
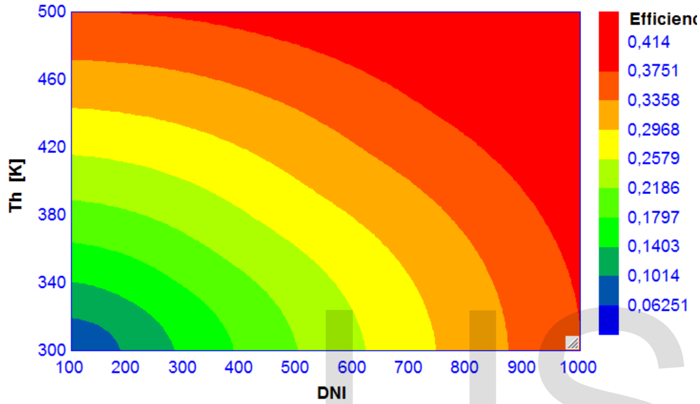


Figure 7: The solar assembly: mirror–receiver–Stirling engine–electric generator [5].

Starting with the study of the influence of solar radiation flux and temperature absorbed by the system to generate electricity



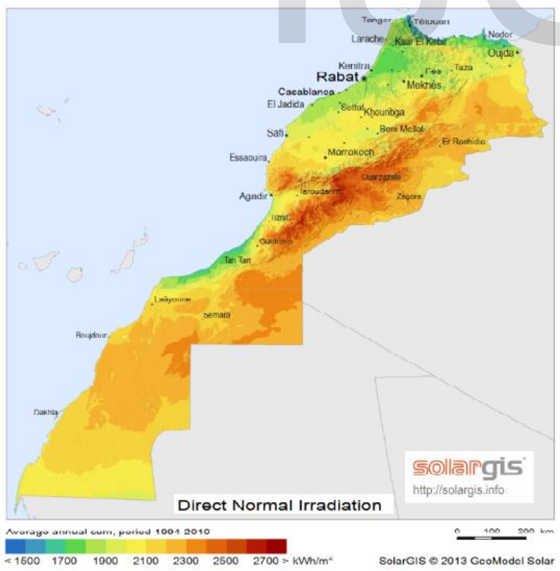
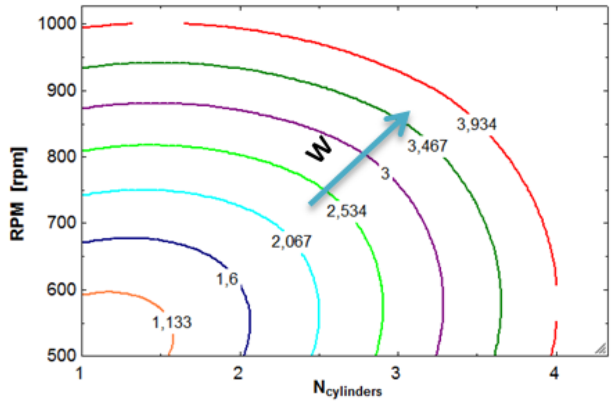


Figure 7: influence parameter DNI & Th on the Performance efficiency



The curve shows that the efficiency increases with the input parameters that play the role of power generation system with Stirling engine. The internal convective heat transfer coefficient practiced is for internal volumes wherever a convection flow is generated by the variation in temperature within the cavity walls and the lower temperature aperture cover. The correlation to learning the convection heat transfer coefficient is subject to the aperture orientation and the Rayleigh number as the internal volume. The internal convection heat transfer coefficient obtained from the Nusselt number correlation for characteristics of cavity receivers are recommended by Arnold et al.

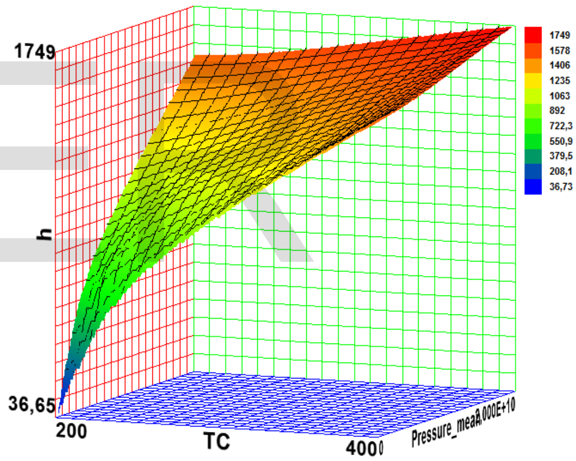


Figure 8: variation exchange coefficient depending on pressure and temperature

IV. Conclusion

The objective of this approach was to develop and provide a methodology for computation, design, and optimization of solar Stirling power systems.

The Stirling engine prototypes created have low outputs because of the considerable disadvantages in the regenerator and the exchanger piston. These losses are primarily expected to external and internal conduction, pressure drops in the regenerator and shuttle effect in the exchanger piston, which depend on the geometrical and physical parameters of the prototype design.

First, the preliminary events verify that the design meets the needs of its practical principle, extracting heat from the lower

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temperature source and giving it to the higher temperature source. Besides it brings useful information of the proposed design, whose performance is still very low and must be improved.
In prospect, it is desired to present concurrently in the model all the optimal parameters acquired, discover the optimal design parameters and consequently the exciting performance.

V. REFERENCE

[1] .Fraser, P. R. (2008). Stirling dish system performance prediction model (Doctoral dissertation, University of Wisconsin-Madison).

[2] .Timoumi, Y., Tlili, I., & Nasrallah, S. B. (2008). Performance optimization of Stirling engines. Renewable Energy, 33(9), 2134-2144.

[3] Timoumi, Y., Tlili, I., & Nasrallah, S. B. (2008). Design and performance optimization of GPU-3 Stirling engines. Energy, 33(7), 1100-1114.

[4] .Scollo, L., Valdez, P., & Barón, J. (2008). Design and construction of a Stirling engine prototype. International Journal of Hydrogen Energy, 33(13), 3506-3510.

[5] .Petrescu, S., Petre, C., Costea, M., Malancioiu, O., Boriaru, N., Dobrovicescu, A., ... & Harman, C. (2010). A methodology of computation, design and optimization of solar Stirling power plant using hydrogen/oxygen fuel cells.Energy, 35(2), 729-73

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