BENCHMARKING OF TWO SYSTEMS FOR TRANSMISSION OF MOTION FOR STIRLING ENGINE DOUBLE ACTION

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Abstract. *In a four-piston Stirling engine configuration Siemens, the displacement of the pistons is governed by the motion transmission element, which converts the reciprocating motion of pistons into rotary motion, curved surface and has a sinusoidal characteristic. This study aimed to evaluate the influence of the geometry of the transmission element rotational motion of the mechanical efficiency of a Stirling engine. Analyses were performed using computer mathematical simulation, where from the geometric data and operating the engine was possible to calculate the mechanical power and efficiency through a mathematical model of thermodynamic first order, also known as the Schmidt model. First analysis was performed using the mechanical efficiency of the transmission element with sinusoidal curve surface. Later, it was implemented in the transmission mechanism of the surface segment-based plans straight, and then performed the analysis of the transmission element with plans straight. The results showed that using the transmission element surface segment-based plans straight engine showed a significant increase in efficiency. Moreover, one can observe an increase in the vibration of the system, making it necessary to develop an appropriate system of balancing.*

Keywords: *theoretical assessment, stirling engines, transmission mechanisms of motion; simulation.*

1. INTRODUCTION

With the market for clean energy heated, much research is being conducted to mature alternative technologies for conversion of renewable energy. One such technology is solar Stirling engine that uses solar radiation as heat source, and using a thermodynamic cycle, it converts thermal energy into mechanical shaft power. Demonstration units Have Reached operational success, Achieving the world's highest-to-grid sun energy conversion efficiency (Stirling Energy Systems, 2008).

The first large-scale solar farm using dish-Stirling technology, rated at 1.5 MW, cam online in January 2010 in Peoria, AZ, and is rated Installations Several hundred megawatts are in the planning stages (Tessera Solar, 2010).

The Stirling engine solar ST-15 "Fig. 1" was developed by Spanish company Ingenieria SL Sostenible Cadiz, located in Barcelona, devoted to projects such as sustainable electrical generation turbines, Stirling engines, air conditioning of buildings projects and research projects and developing new products.

The ST-15 was designed to generate 18.5 kW of electric power, of which 3.5 kW to supply its auxiliaries, such as water pumps, radiator, control system and the engines of solar tracker. The working fluid is the engine of Helio, and can operate with compressed air. The configuration of the Stirling engine is a dual-action, or Siemens, four-piston, which gives a slim profile, lightweight and long shadow which produces little in the parable of mirrors. The parable of the solar tracker has an area of 75 m^2 and was developed by a specialized company in this sector. Engine efficiency varies with solar radiation, reaching 25% in the period of maximum solar insolation.

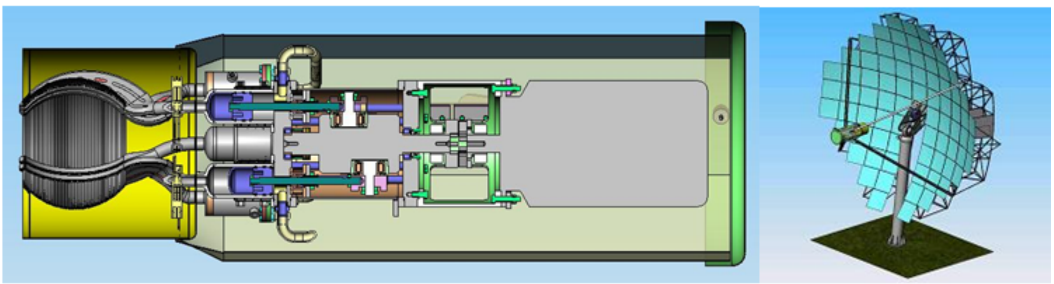

Figure 1. Simplified general scheme for the ST-15 solar Stirling engine.

"Table. 1" contains the main technical data for the Stirling engine ST-15.

The principle of operation of the engine is based on the Stirling cycle, where a pressurized gas is compressed by the piston in the bottom of the cooling zone and subsequently the gas is displaced, also with the help of the piston to the hot

Table 1. Technical data of ST-15 solar Stirling engine.

Engine	
Piston diameter	90 mm
Piston stroke	65 mm
Number of pistons	4
Working fluid	Helium or Air
Internal pressure	55 bar
Final separation at the top of piston (expansion)	1 mm
Final separation at the top of piston (compression)	4 mm
Phase difference between expansion pistons and compression pistons	90 °
Working gas temperature inside the heater	650 °C
Working gas temperature inside the cooler	70 °C
Absolute mean pressure	58 bar
Maximum speed	1020 rpm
Data from the hot heat exchanger (heater)	
Material	AISI-316 L
Quantity of tubes	48
Internal diameter	4 mm
Length	250 mm
Data from the hot heat exchanger (cooler)	
Material	AISI-316 L
Quantity of tubes	60
Internal diameter	4 mm
Length	138 mm
Regenerator	
Quantity	184
Material	AISI-316 L
Regenerator diameter	90 mm
Wire diameter	0,1 mm
Length	37 mm
Porosity	0,685

zone, where absorbs heat and expands, producing force on the piston. It is because the transmission mechanism of the force on the pistons (reciprocating rectilinear motion) is converted into torque (rotational motion).

Currently, there are several types of transmission systems of movement that can be implemented in the fourth piston Stirling engines for distributed round, the geometry of Ross-Triebwerks, the combination of the Z axis (Z-crank) and swash plate (wooble-plate) and mechanism of sliding plate (Swashplate Mechanism). “Figure. 2” illustrates each of these systems.

The transmission mechanism of the engine ST-15 “Fig. 3” whose geometry is a central axis, the larger houses a deep groove whose profile is sinusoidal around the circumference of which the beginning and end of the sinusoid coincide at one point. Within this groove ball bearings are housed four where the pistons are fixed. Since the central axis starts its rotational movement, left the bearings of the pistons traverse the sinusoidal profile, resulting in reciprocating motion and straight toward the axis.

In this context, this study aimed to evaluate the influence of geometry element transmission of rotary motion into the mechanical efficiency of a solar Stirling engine ST-15.

2. EXPERIMENTAL PROCEDURE

To simulate the engine, a mathematical model of isothermal second order was made in Excel software, from the program prepared by Martini (Martini, 1983). This mathematical model is a relatively simple and low computational consumption, particularly useful for the optimization of engines since the beginning of its design. Initially, a brief computational procedure determines the basic power and heat input. The basic power then is degraded by various losses identifiable, and more heat input is added according to the known thermal losses in real engines of this type. Consequently, an estimate is made as to the actual power output and heat input actually required.

The course of Schmidt, well known for these engines, also called the Stirling cycle is the thermodynamic cycle used to simulate adiabatic second order mentioned above. The thermodynamic definition of a Stirling cycle is an isothermal

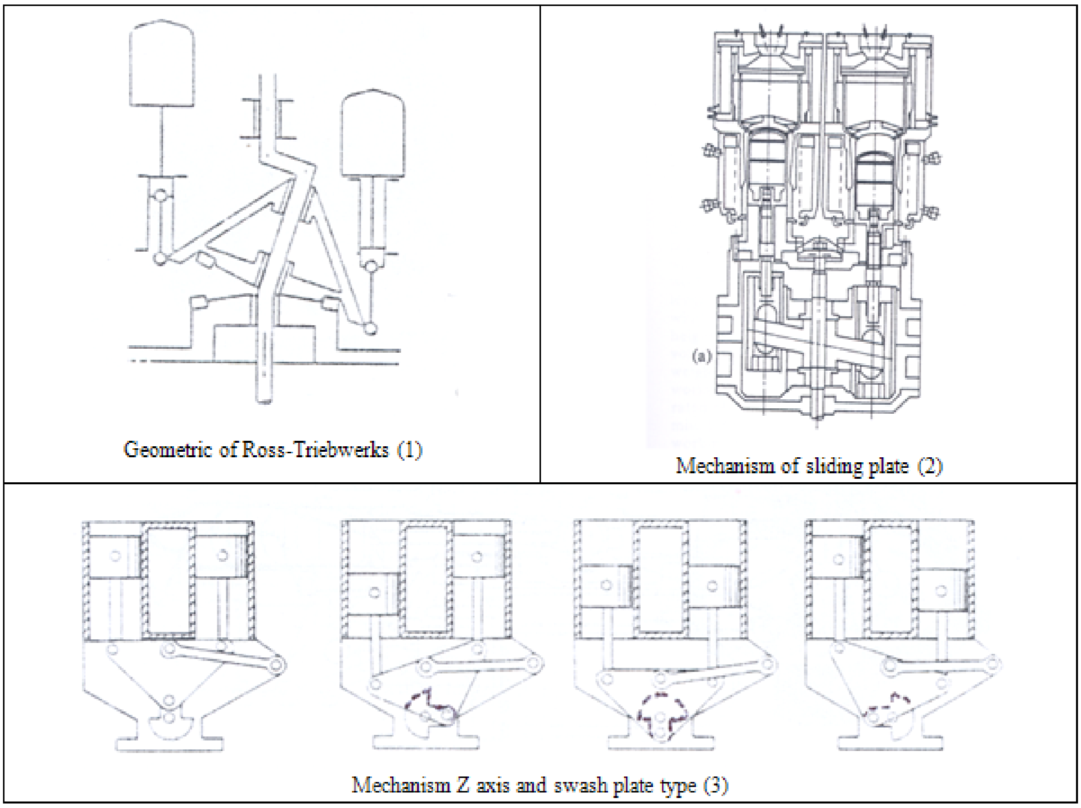

Figure 2. Types of mechanisms of transmission of motion for double-acting Stirling engines (Siemens)(Werdich and Kübler, 2003)

a) b)

Figure 3. Photos of the shaft of the transmission mechanism. a) shaft supported on the structure of the medial motor. b) insulated shaft

compression and expansion and a heating and cooling at constant volume.

The data used for the execution of the simulation are presented in "Tab. 1". It is also necessary to know other data as the temperatures of hot and cold heat exchangers, environmental conditions, consumption of auxiliary equipment and electromechanical equation of motion of the pistons usually lagged 90 ° between them.

For comparison of two transmission mechanisms of movement has changed the equation of the sinusoidal profile, keeping all other variables and equations fixed.

During the simulation, every 1 ° of rotation axis, we calculated the positions of the pistons in relation to a reference as well as their velocities and accelerations, internal pressure instantaneously within each of the four chambers formed by the upper side of a piston and the side bottom of the next piston, the temperatures of the working fluid in each zone of the chamber (with 5 zones: hot heat exchanger, a channel of connection between the exchanger and the hot stove, stove,

stove pipe between the exchanger and the cold, cold heat exchanger) And other data relating to system efficiency, electric power generated. The mechanical power was calculated by summation of each delta pressure multiplied by delta volume divided by 2 for each of the angles of the axis, as showed below in the “Eq. 1” :

$$P = \sum_{1}^{360} \frac{\Delta P_\alpha \Delta V_\alpha}{2}$$

Where α represents the angle of rotation axis $1\,^\circ \leq \alpha \leq 360\,^\circ$ and $\Delta P = P_{\alpha+1} - P_\alpha$. (1)

Since the delta volume depends on the equation of the profile of the transmission mechanism, it was possible to calculate and compare the performance of each of these mechanisms in relation to mechanical power. At the same time, we also can calculate the velocities and accelerations of the piston based on the same equation of the profiles, since for a same rotational speed, the time between an angle more than 1 is the same between them and so the speed can be calculated as delta time offset multiplied by the delta and acceleration can be calculated as the delta by delta time speed.

3. RESULTS

The profile of slot commonly used is sinusoidal, since the new profile is a modification of the proposed sinusoidal, where the "valleys"and "ridges" of the sinusoid are flatter and steeper slopes. “Figure. 4” illustrates the difference between the profiles used.

The advantage of using this new profile again based on the principle of engine operation. This is because with the peaks and valleys flattened the piston spends more time in the zones of heating and cooling, resulting in greater absorption and heat rejection by the working fluid and therefore more thermal energy is converted into mechanical power.

“Figure. 5” shows the graph of pressure versus the volume of the Stirling cycle for both cases and this one can notice that the inner area, which corresponds to the work produced is higher for the case of modified sinusoidal profile, as predicted theoretically.

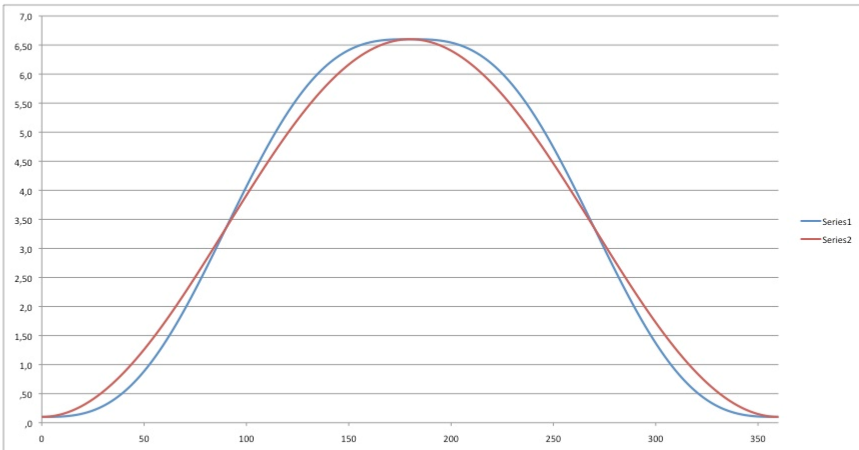

Figure 4. Difference between the sinusoidal profiles. In red, the most commonly used profile. In blue the profile slightly modified.

As each piston is at a certain point of the profile, each of them will have a different velocity and acceleration between them. This causes oscillations and vibrations of the whole.

“Figure. 6” graphically shows these oscillations for each profile considered, and additionally shows the oscillations caused by motion transmission mechanism comprising the traditional crank drive.

One can see from the graph that the behavior of the oscillations resulting from the use of profile sinusoidal and the crank drive system are behaved and follow a sinusoidal pattern of period and frequency proportional and fixed speed of rotation of the shaft. For these cases a balance is sufficient to annul the vibrations caused by accelerations of the pistons.

As for the case of the modified profile, it is noted that this presents a different behavior, with the same period, but with harmonic frequency. These harmonics cause the share balance is inadequate and insufficient, making it necessary a vibration damping system specific, in this case, specifically designed to cancel this type of fluctuation.

4. CONCLUSION

Through computer simulations, it was found that using the sinusoidal transmission mechanism, the Stirling engine ST-15 produced under the employed conditions of temperature and pressure, at a net power output shaft of 5.962 kW.

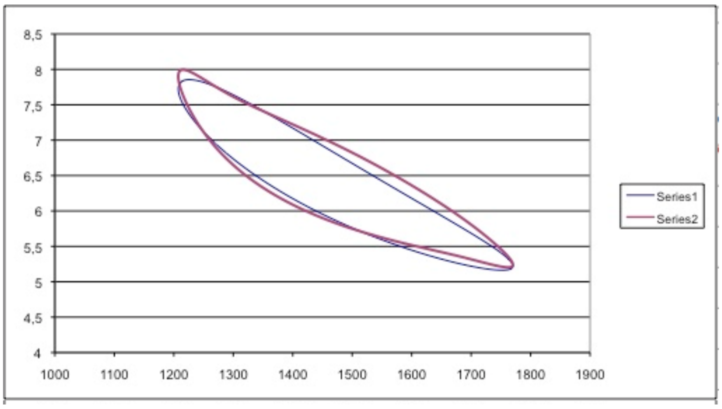

Figure 5. Chart pressure x Volume. In blue the curve corresponding to the sinusoidal profile. Red curve corresponds to the profile slightly modified.

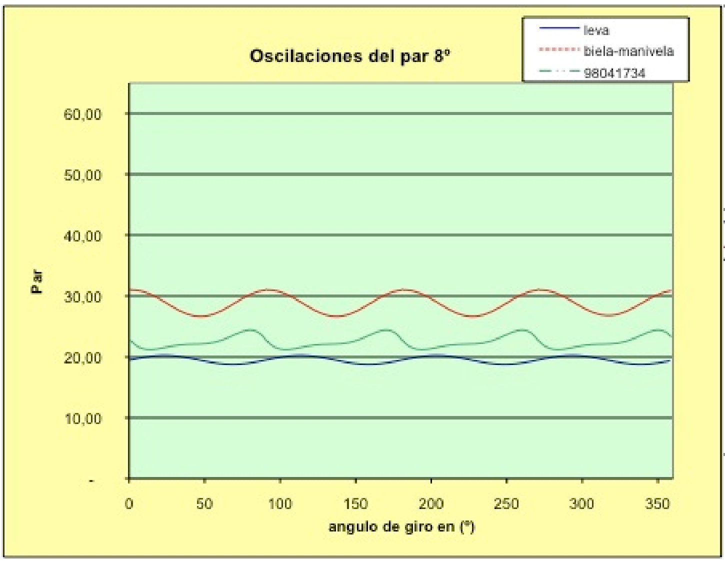

Figure 6. Oscillations caused by different types of transmission mechanisms of movement. Blue sinusoidal profile, the modified profile in green and red traditional crank drive

When using the new profile, sinusoidal, the power net on the output shaft was 6.057 kW, ie, there was an increase of 1.59% on mechanical power.

Despite gains in the mechanical power, it was found that when employing the new sinusoidal profile, strong accelerations and decelerations, interspersed by periods of inactivity inertial sometimes cause a strong vibration in the motor assembly, the complex pattern, requiring an astute system counterweights to negate the effect. This did not occur with the mechanism of sinusoidal profile, which, although also present vibration, this has a more favorable performance implementation of a balance that would nullify the vibrations.

However, the increase in mechanical power not offset the extra use of a complex mechanism of balance, and the sinusoidal profile as indicated for use by the fourth piston Stirling engine configuration Siemens.

5. ACKNOWLEDGEMENTS

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