Alpha Stirling Engine - SUNNYTECH SC005

Course: THERMODYNAMICS II

Jonatan Cano González

Santiago Gómez Jiménez

Sebastián Bedoya Atehortúa

Tatiana Serna Tavera

University of Antioquia, Faculty of Engineering, Mechanical Engineering Program

Abstract.

In this article, we aim to elucidate the design and development process of an Alpha Stirling engine prototype by a group of engineering students from the University of Antioquia. Additionally, we seek to highlight the setbacks and challenges encountered during its manufacturing process, serving as a future guide for projects aiming to create similar prototypes.

Keywords:

engineering, Stirling engine, alpha, prototype, design, manufacturing, thermodynamics, 3d printing.

Introduction

The Stirling engine is a thermal engine that operates based on a thermodynamic cycle of gas compression and expansion called the Stirling cycle. Unlike conventional internal combustion engines, it utilizes the heating and cooling of a fluid, typically air, to convert thermal energy into mechanical energy. The importance of the Stirling engine lies in its energy efficiency, its ability to utilize various heat sources, and its low environmental impact, not to mention that they are considerably silent engines. Currently, Stirling engines are in a state of ongoing exploration and advancement due to the aforementioned advantages. As technological advancements are made, it is expected that these engines will play an increasingly important role in the transition towards cleaner and more sustainable energy sources. Therefore, it is crucial to engage in practical involvement in their manufacturing to fully understand their operation. As engineering students, the best way to acquire the necessary knowledge is by fabricating a functional prototype that faithfully represents its operation. During this process, several problems and challenges will need to be resolved, which will undoubtedly enrich understanding of the subject.

Some potential alternative fluids for the Alpha Stirling engine:

As mentioned before, the Stirling engine typically uses air in its compression and expansion cycle. However, this doesn't mean that there aren't other fluids that could be more promising in this model. Due to their thermal properties and ability to maximize the efficiency of the Stirling cycle, the following fluids can be highlighted:

- Hydrogen: It has higher thermal conductivity and can reach high temperatures, indicating that it could heat up more quickly than conventional air. Additionally, its lower density implies less friction losses and higher engine efficiency.
- Helium: It can be an interesting fluid to use due to its viscosity and its ability to operate at extremely low temperatures, enabling the Stirling engine to function in ambient conditions where it couldn't operate with air.
- Ammonia: It has a high heat transfer capacity and is commonly used in refrigeration systems. Although it may not be considered a primary option, it is important to consider it and make the appropriate choice based on the application and operating conditions.

Design & construction

The main parts of an alpha-type Stirling engine are the following:

1. Hot Cylinder: it is heated from an external source, such as a burner or solar energy. It contains the expansion space where the working fluid expands and gains thermal energy.
2. Cold Cylinder: This part is cooled externally, usually by a heat sink or cooling fluid such as water. In contrast with the hot cylinder, this one contains the compression space where the working gas is compressed and releases thermal energy.
3. Displacer: with a piston-like shape, the displacer is the component that moves the working gas in the cold cylinder. It is usually driven by a mechanical linkage (crank).
4. Power Piston: its purpose is to convert the pressure changes of the working gas into mechanical work. It is linked to a crankshaft or other mechanism, converting the linear motion into rotational motion.
5. Heat Source: This part provides the necessary heat for the system, specifically to the hot cylinder as mentioned before.
6. Heat Sink: This component is responsible for dissipating heat from the cold cylinder. Its work is to ensure a lower temperature in the cold cylinder, compared with the hot cylinder. This allows the engine to operate based on the temperature gradient.
7. Crankshaft: The crankshaft takes the linear motion from the power piston and converts it into rotational motion. It can transfer the mechanical work generated by the engine to an external load or device.
8. Flywheel: The flywheel is a heavy rotating disk connected to the crankshaft. It provides rotational inertia and helps to smooth out the engine's rotational motion, which ensures a more consistent and continuous power input.

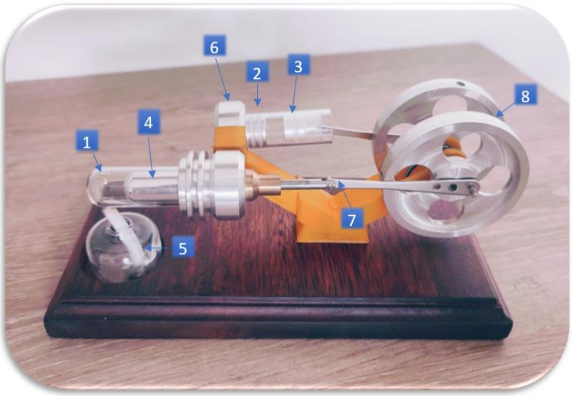

Figure 1 Parts of the alpha-type Stirling engine.

The dimensions for the design and construction were taken from an existing model presented in class by the teacher using a vernier and from a commercial model.

Figure 2 Commercial model of the prototype

This image was taken from: https://www.amazon.com/-/es/Sunnytech-caliente-Stirling-educaci%C3%B3n-electricidad/dp/B00LWXLERM

Subsequently, CAD models were created in Autodesk Inventor for each component, allowing the creation of blueprints for subsequent manufacturing.

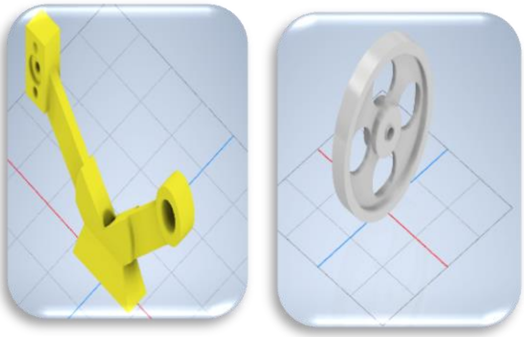

Figure 3 CAD designs in Autodesk Inventor.

The selected material was aluminum, as it is affordable and easy to work with using CNC machines.

Both the flywheels and cranks, along with their shafts and the base of the cold cylinder, were manufactured using CNC machining.

Figure 4 CNC machining at the laboratory.

In the original designs, the cold and hot cylinders were made of stainless steel. However, in this design, it was decided to purchase them in glass as they allow for the visualization of piston movement and work well in the system.

Since the piston is a critical component for the system's operation and there was not enough time for its fabrication in the CNC laboratory, it was decided to purchase it.

Figure 5 Purchased piston.

The support was 3D printed using ABS as the raw material. Due to an air leakage issue with the first prototype, it was necessary to manufacture a second prototype with a better fit and add rubber gaskets to prevent further leaks.

Figure 6 3D-Printed base.

As some drill bits in the laboratory were worn out and not all the necessary measurements were available, it was decided to purchase specific drill bits for each hole to achieve the highest possible precision with respect to the design.

A small glass container was selected as the heat source and was also purchased to contain the fuel. Initially, 70% alcohol was used as the fuel, but optimal performance was not achieved as the engine took a long time to start and was slow. Therefore, it was ultimately decided to use 96% alcohol, which provided the best results. This alcohol was burned using a wick as the burner.

Figure 7 Glass container used with 96% alcohol.

The base was constructed from wood, and the space where the heat source is located was adapted accordingly.

Figure 8 Base and final model of the prototype.

Ideal thermodynamic cycle

In the study of ideal power cycles, it is necessary to consider certain idealizations and simplifications such as:

1. The cycle does not involve any friction.
2. Expansion and compression processes take place in a quasi-equilibrium manner.
3. Heat transfer through pipes is negligible.

Stirling cycle

This cycle operates between a heat source at T_H and a sink at T_L, and both the heat-addition and heat-rejection processes during the cycle must take place isothermally. This process differs from the Carnot cycle in that the two isentropic processes are replaced by two constant-volume regeneration processes [1].

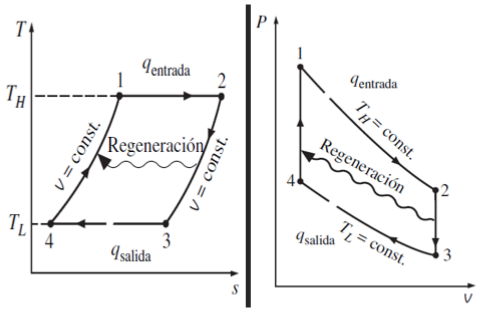

Figure 9 Diagram T-s and P-v for Stirling cycle [1]

Figure 9 shows the T-s and P-v diagrams of the Stirling cycle, which is made up of four totally reversible processes:

1-2 Process: T = constant expansion (heat addition from the external source)

2-3 Process: v = constant regeneration (internal heat transfer from the working fluid to the regenerator)

3-4 Process: T = constant compression (heat rejection to the external sink)

4-1 Process: v = constant regeneration (internal heat transfer from the regenerator back to the working fluid)

The efficiency of the Stirling cycle is expressed by Equation 1

$$\eta_{th,Stirling} = 1 - \frac{T_L}{T_H}$$

Equation 1

Alpha Stirling engine

The Stirling engine is recognized as a thermodynamic device comprising two distinct cylinders, each housing a piston, strategically arranged at a 90-degree angular displacement from one another. This deliberate phase offset facilitates the transfer of the working fluid between the cylinders, where it undergoes cycles of heating and cooling. These thermal variations engender the conversion of thermal energy into mechanical work. We can analyze the cycle of the alpha Stirling engine in four strokes as shown in Figure 10.

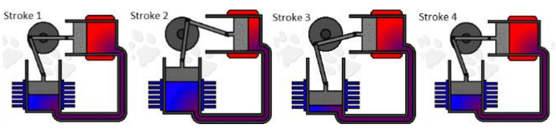

Figure 10 Four Strokes in an Alpha Stirling engine cycle [2].

Stroke 1 – Expansion: Most of the air within the engine is in the hot cylinder. The gas heats, expands and drives both pistons inwards to the crankshaft.

Stroke 2 – Transfer: The momentum of the flywheel carries the engine through the next 90 degrees, this causes most of the air to be tranferred over to the cold cylinder.

Stroke 3 – Contraction: The majority of the expanded gas has shifted over to the cold cylinder, it cools and contracts which displace both pistons outwards, away from the crankshaft.

Stroke 4 – Transfer: The momentum of the flywheel carries the engine through the next 90 degrees, this causes most of the air to be transferred over to the hot cylinder, completing the cycle.

Measurement of generated power

Based on the functional prototype that was developed, the measurement of generated power was performed in a practical and straightforward manner. With the assistance of a generator and an LED, the power was determined using Equation 2. For this purpose, several pairs of pulleys were 3D-printed (Figure 11) since this Stirling engine prototype has limited load capacity. It was tested with various configurations until achieving a brief and low-intensity illumination of a red LED.

$$P = I * V$$

Equation 2

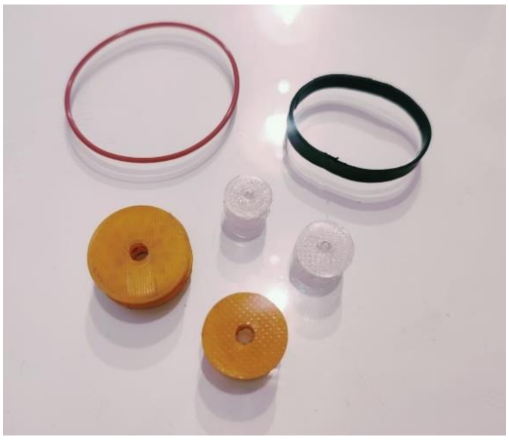

Figure 11. 3D-printed pulley.

For a typical red LED, its threshold values for both current and voltage are approximately 1.6 V and 15 mA, respectively [4]. The measurements conducted are consistent with these values. Therefore, the power generated by our Alpha Stirling engine prototype is around 0.024 W.

Some alternative methods for determining the generated power and thermodynamic states.

- The use of Ansys software in conjunction with Finite Element Method (FEM) and Computational Fluid Dynamics (CFD) allows for the determination of values for each thermodynamic state, considering the necessary boundary conditions.
- Schmidt's theory, Schmidt carried out mathematical modeling and Stirling engine analysis. His theory is based on harmonic pistons and device nodes movements, ideal isothermal expansion and compression and ideal regeneration [3].
- By coupling volume and pressure sensors, it is possible to obtain the remaining thermodynamic values at each state. Using EES software, one can calculate the indicated mean effective pressure (IMEP) and indicated power.

Conclusions

- The future prospects of the Alpha Stirling engine are promising due to its energy efficiency, ability to utilize various heat sources, and its potential integration into renewable energy systems. As the demand for sustainable energy continues to grow, these engines are likely to play an increasingly important role in generating clean and efficient power.
- In the manufacturing process of the engine, one of the most important and critical components to produce is the piston. It is crucial to ensure the functionality of this piece within the mechanism. If it cannot be commercially obtained, a considerable amount of time must be dedicated to its proper fabrication.
- By changing the materials of certain components, such as the cold cylinder and the hot cylinder, we directly affect the performance of the prototype. The coefficient of friction differs between glass and stainless steel. We also assume that the durability of these pieces is lower. However, since it is an educational prototype, this does not pose a major problem and actually helps us better observe the mechanism's functioning.

References

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