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DESIGN AND FABRICATION OF ALPHA STIRLING ENGINE

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Abstract - *This paper details the design and fabrication of an Alpha Stirling engine, aiming to create a cost-effective prototype. The Stirling cycle, featuring one hot and one cold cylinder, is employed as a dynamic system. Standard dimensions are used for design parameters and control tools. Despite its high volume ratio, the engine can become unstable at high temperatures. Stirling engines convert heat energy into electricity using solar energy as the primary source. The goal is to recycle waste heat from gas exhausts. Stirling engines are environmentally friendly, releasing no pollutants. Fabrication costs are lower compared to other engines. Sketchup is used for design, with 3D printer for parts printing and surface finishing to minimize friction. The theoretical power output is 0.785 kW at 300 rpm, with a cylinder diameter of 36mm, and an estimated efficiency of around 40%.*

***Key Words*: Alpha Stirling Engine, Heat Energy, Mechanical Energy, 3D Printing, Waste**

1. INTRODUCTION

The Stirling engines works on a closed thermodynamic cycle as they are external heat engines, so we maintain temperature difference between the two cylinder one is hot cylinder and other is cold cylinder. Solar Stirling engine uses solar radiation energy as external heat source for heating working fluid (gas) to convert thermal energy into electrical energy. There is an ideal Stirling engine that has an efficiency of 40%, in contrast to others engines like the otto engine, which has 25% and the diesel engine, which has 35%. Stirling engine work by isochoric and isothermal processes. Stirling engines have a higher capital cost and are heavier than internal combustion engines; however, they require a lower maintenance cost. It is more efficient than other engines, but controlling it at high temperatures can be challenging.

1.1 Literature Review

- **B. Kongtragool Et Al, 2003 [1]** reviewed on solar Stirling engine and low temperature differential Stirling engine to find feasible design and workable solar-powered low temperature Stirling engine.

- **K.G. Maheswaran Et Al, 2017 [2]** provides an explanation of how a beta type Stirling engine is constructed and they are external combustion engines that run on Stirling cycles. They use heat sources such as solar energy and agricultural waste like paddy straw, sugarcane leaves, wheat stalk, groundnut shell, coconut husk, etc. The efficiency of these engines is comparable to the theoretical Carnot efficiency, making them suitable for stationary power generation.

- **K. Dinesh Et Al, 2014 [3]** describes how low-cost Stirling engines can be built and utilized for green energy application, including theoretical background, various designs and parameters.

- **Mohamed Abbas Et Al, 2008 [4]** proposed thermal analysis of Stirling engine using parabolic concentrator in paper. This paper shows various energy loses that engine does when converting heat into electrical energy.

- **Muhammad Hassan Et Al, 2021 [5]** paper showcases that using CAD tools, the design and fabrication of a 90-degree alpha Stirling engine were performed, and the power outputs from the Stirling engine were analyzed at every different temperature. At various points, external heat input was increased to observe the engine's stability.

- **Najafi. G Et Al, 2015 [6]** paper describes about design of gamma Stirling engine and using biomass energy as heat source of the engine. This shows gamma Stirling engine behavior at different temperatures.

- **Snyman. H Et Al, 2008 [7]** published paper on design analysis of Stirling engine, made attempts to create new design of engine which are feasible, low cost and produces more power.

- **Vishal Gehlot Et Al, 2014 [8]** discussed an alpha Stirling engine prototype is built with an emphasis on developing a new approach to development and fabrication. For maintaining control of dynamic systems, the Stirling cycle is recast in this paper.

- **Yaseen H. Mahmood Et Al, 2018 [9]** this paper investigated the properties of Gamma Stirling engines produced using low-cost materials, and their efficiency in relation to temperatures and pressure.

1.2 Research Gaps

Many researchers in the past had performed experiments on the Stirling engine and proposed design adjustments and fabrications methods. Most of them have analyzed Stirling engines in Ansys, but we, in this paper, are designing and fabricating Stirling engines with different design dimensions. Most researchers have made studies on beta and gamma Stirling engines. Here, we are studying the range of output electricity for various inputs of temperatures to an alpha Stirling engine. i.e., when the temperature parameter is varied, electricity output at the outlet is noted.

2. MATERIALS AND METHODS

In the present chapter the various components were designed to fabricate the parts and has been discussed along with their specifications and the working process of the prototype has also been discussed. Parts were designed using Solid Works.

Design of Parts:

1. The pumps' mount: Fig-1 shows the part was used as a support to hold the pumps (10ml Syringes) used to rotate the wheels.

Fig-1: The Pumps' Mount

2. The connecting rods: Fig 2 shows the two rods that were used to connect the wheels with the pumps, maintaining stability of a mechanical system.

Fig-2: The Connecting Rods

3. The Connecting Rods' Heads: Fig-3 shows the two heads that were used to connect the pumps' tops with the rods.

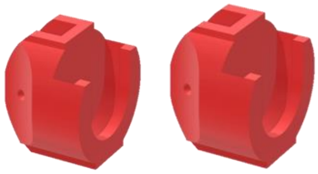

Fig-3: The Connecting Rod's Heads

4. Flywheel: Fig-4 shows the design view of the flywheel. Flywheel is a circular disc which rotates when shaft and counter weights rotates. Flywheel is fixed to delivery power from an engine to machine.

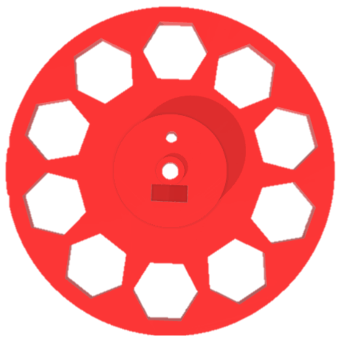

Fig-4: Flywheel

5. Pistons (Glass syringes): Fig-5 shows the two glass syringes that were used as pistons which have diameter of 22mm. Pistons are used to compress the air inside the cylinder and transfer energy.

Fig-5: Glass Syringes

6. The wheels' mount: Fig-6 shows the design view of wheel's mount. This part is used to support the wheels and hold them in place.

Fig-6: The wheels' mount

Methods:

The Stirling engine prototype needs to be done using two main steps. First, the main body of the prototype needed to be constructed using accurate measurements. So, (Sketch up) program was used to build the prototype body as a software file, and then the prototype was built in the Fab Lab (Fabrication Laboratory) using the 3D Printer. The second process is the manual construction of the prototype. This part was done using several steps: First, the pumps' and the wheels' mounts were set to a wooden base that grips the whole prototype. Second, the wheels were connected to their mount by using a 1mm thickness nail as a connector between the two wheels, and some oil was used to increase the smoothness of scrolling the wheels. Then, the connecting rods and their heads parts were connected to each other and then attached to a point in the wheels that is away from its center by 1cm by using a 0.5mm nail as a connector that the rod can spin around while moving. After that, the pumps (2qty 10ml glass syringes) were connected to each other by a 2mm diameter pipe and then they were attached to their mount and finally connected to the heads of the rods. Finally, a motor was set on the wooden base and then connected to the wheels to convert the kinetic energy to electricity while the prototype is working.

3. WORKING PROCEDURE

Solar Stirling engine process

- An engine starts when an external heat source, such as waste, is provided at the end of a hot cylinder.
- Stirling engine utilizes gas as a working fluid. As when the external heat source was activated, heat transfer increased to the hot cylinder, which increased the temperature of the gas molecules. During the heating process, gas molecules expand inside the hot cylinder as the temperature rises.

4. By expanding the gas, the piston is pushed away WORKING PROCEDURE

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- By expanding the gas, the piston is pushed away by the pressure, which starts the flywheel in motion.
- Displacer piston movement causes gas to move from a cold cylinder to a hot cylinder and vice versa.
- Through the gas exchange tube, expanded gas or heated gas molecules move from the hot cylinder to the cold cylinder. Cooling the hot gas is accomplished by the fins in a cold cylinder.
- When the gas has been cooled, the piston compresses it in the cold cylinder, allowing it to move to the hot cylinder, where the cycle repeats. This causes the flywheel to rotate through the motion of piston expansion and compression.
- A flywheel is attached to the motor which rotates to generate the electro flux and to produce the electricity.

5. CALCULATIONS

The present chapter discusses the calculations obtained from the theoretical values.

THEORETICAL CALCULATIONS:

- Swept volume = $(\pi \div 4 \times D^2 \times L)$

  $= (\pi \div 4 \times 0.036 \times 0.124)$

  $= 129.747 \times 10^{-6}\ m^3$
- Clearance volume = 5% of swept volume

  $= 5 \times 129.747 \times 10^{-6}$

  $V_2 = 6.487 \times 10^{-6}\ m^3$

  V_1 = Swept + Clearance

  $V_1 = 129.747 \times 10^{-6}\ m^3 + 6.487 \times 10^{-6}\ m^3$

  $= 136.234 \times 10^{-6}\ m^3$
- Compression ratio r

  $= V_1 \div V_2$

  $= (136.234 \times 10^{-6} \div 6.487 \times 10^{-6})$

  $= 21.001$
- 1-2 isentropic process $T_2 \div T_1 = (V_1 \div V_2)^{\gamma-1}$

  $= (136.234 \times 10^{-6} \div 6.487 \times 10^{-6})^{1.4-1}$

  $= 1057\ K$

According to ideal gas equation, $P_1 \times V_1 = m \times R \times T_1$ Mass of air (m) =0.001kg,

Temperature of air = 313 K

$P_1 \times 136.234 \times 10^{-6} = 0.00159 \times 0.287 \times 313$

$P_1 = 0.659 \times 10^6\ kPa$

$P_2 \div P_1 = (1 \div r^{\gamma})$

$P_2 = 1 \div (21^{1.4}) \times (0.659 \times 10^6)$

$= 9.284 \times 10^6\ Pa$

- 2-3 Constant Volume Process $V_3 = V_2$

  $P_3 \times V_3 = m \times r \times T_3$

  $P_3 \times 6.487 \times 10^{-6} = 0.001 \times 0.287 \times 500$

Supply Heat temperature (T_3), assume $T_3 = 500k$ $P_3 = 22.12 \times 10^6$ P

- Heat supplied = m × C_v × (T_2 - T_3)

  = 0.001 × 0.707 × (10547-500)

  = 0.39 kJ/kg
- 3-4 isentropic process $P_3 \div P_4 = r^{\gamma}$

  $P_4 = 22.12 \times 10^6 \div 21^{1.4}$

  $P_4 = 31.16 \times 10^4$
- 4-1 Constant volume process $T_4 \div T_1 = P_4 \div P_1$

  $T_4 = 31.16 \times 10^4 \times 313 \div (0.659 \times 10^6)$

  T_4 = 147.99 K
- Heat Rejected = m × C_v × (T_1 - T_4)

  = 0.001 × 0.707 × (313 – 147.9)

  = 0.11 kJ/kg

6. Work done = Heat Supplied – Heat Rejected

= 0.39 - 0.11 = 0.28 kJ/kg

7. %Efficiency = (work done/Heat supplied)

= (0.28 ÷ 0.39) × 100 % = 71.7 %

8. Performance calculation

8.1 Area = π × D × L

= 3.14 × 0.036 × 0.124

= 0.014 m^2

8.2 Force = Pressure × Area Assume,

P = 1 bar

Force = 1 × 10^5 × 0.014

= 1.4 kN

8.3 Torque = Force × Radius Radius of flywheel = 18 mm

= 0.018 m

Torque = 1.4 × 0.018

= 0.025 kN-m

8.4 Power = (2π × N × T) ÷ 60 KW

= (2π × 300 × 0.025) ÷ 60 KW

= 0.785 kW

9. Therefore, Power generated from heat supply 500K with cylinder diameter 36mm is 0.785kw.

RESULT

The results obtained from the theoretical calculations of the alpha Stirling engine are discussed in this chapter. The theoretical calculations to find the power output from specific heat supply was performed assuming the heat supply as 500K with our cylinder diameter of 36mm. The theoretical power output is 0.785 kW at 300 rpm. Because of fabrication difficulties while machining the Stirling engine was not performing. An attempt was made to design the Stirling engine where the design of the engine went well but, due to fabrication errors the engine is not working.

10. CONCLUSIONS

The following conclusions can be derived from the project:

1. The design of the Stirling engine provides the necessary data for the comparison of several aspects of the Stirling-cycle engine.
2. The theoretical efficiency is more than 70% for respective supplied heat.
3. The Stirling cycle is useful in the marine environment because it can be driven by any heat source, such as solar, exhaust gases, or any other source of heat.
4. Using an intricate design was a very big problem which made the first attempt fail After our first test, it was conducted that the simply designed Alpha engine was one of the most important success ingredients.
5. The friction is a very important influential factor effect on any project that produces kinetic energy.
6. When horizontal, gravity causes more friction on the side of the syringe pistons. This slows the engine. With a slow engine, heat is not removed very fast by the engine. So, the temperature of the cylinder rises.

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