DESIGN AND FABRICATION OF ALPHA STIRLING ENGINE

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Abstract - *This paper describes a method for designing and fabricating an Alpha Stirling engine with the goal of building a working prototype. The Stirling cycle is a dynamic system which have one hot and one cold cylinders. Standard dimensions are used to calculate all design parameters and control tools. This type of engine has a high-volume ratio, but becomes unstable on reaching high temperature. Stirling engines convert heat energy into electricity without polluting the environment using solar energy as a primary source. Solar energy is one of the world's fastest-growing renewable energy sources. The ideal Stirling engine would be as efficient as a Carnot engine, so it can generate more power than normal solar panels. Stirling engine won't release any kind of pollution into the environment. Fabricating of Stirling engine required low cost than compared to another engines. We used SolidWorks to design the engine parts with standard dimensions for specific power output. After designing, the parts were fabricated using CNC machining and surface finish is done to avoid friction between the parts. We calculated the theoretical power output of the engine is 0.785 kW at 300 rpm with cylinder diameter of 36mm. The theoretical efficiency is around 40%.*

***Key Words*: Alpha Stirling engine, heat energy, Carnot engine, SolidWorks, CNC, Solar energy**

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. This paper results shown low temperature air are given more energy.
- **Krissadang Sookramoon Et Al, 2022 [2]** describes in paper about using of biomass incineration to heat Stirling engine to produce electric power.
- **K.G. Maheswaran Et Al, 2017 [3]** 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 [4]** 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 [5]** 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 [6]** 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 [7]** 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 [8]** 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 [9]** 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 [10]** 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: We designed 23 parts of Stirling engine and some of them are

1.Crank Shaft: Fig-1 shows the design view of the crank shaft with length 35mm and diameter 5mm. crank shaft is responsible for converting a linear motion to a rotational motion.

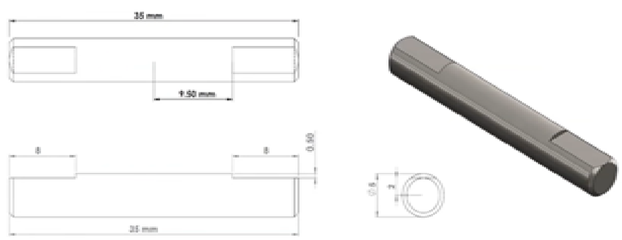

Fig-1: Crank Shaft

2. Counter Weight-A and Counter Weight-B: Fig-2 shows the design view of the counter weight-A and counter weight-B. Counter weights are used for applying an opposite force, provides balance and stability of a mechanical system.

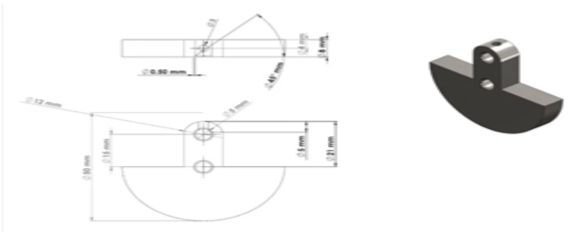

Fig-2: Counter Weights A&B

3. Cylinder: Fig-3 shows the design view of the cylinder. Here the air is compressed and expanded.

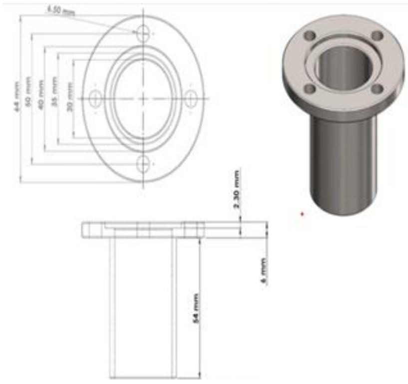

Fig-3: Cylinder

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.

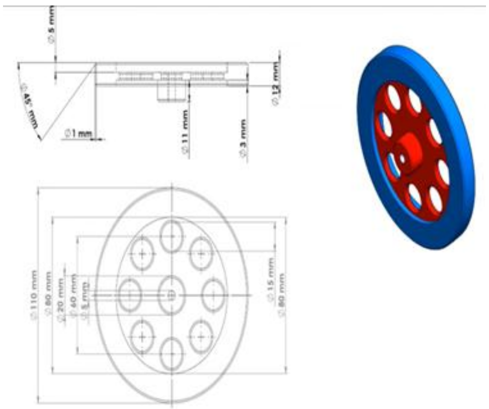

Fig-4: Flywheel

5. Piston: Fig-5 shows the design view of piston which has diameter of 30mm. Piston is used to compress the air inside the cylinder and transfer energy.

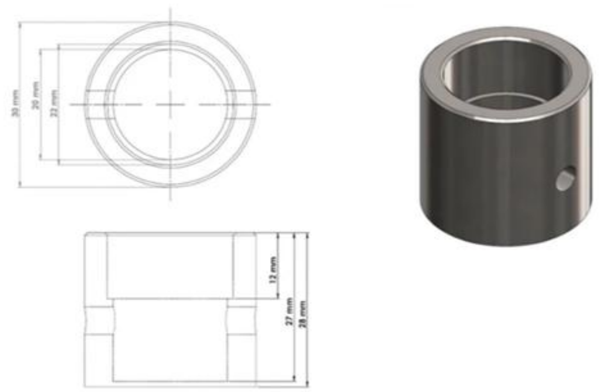

Fig-5: Piston

6. Cross Head: Fig-6 shows the design view of cross head. Cross head is a mechanism used as part of slider-crank linkages of long reciprocating engines to eliminate sideways pressure on the piston.

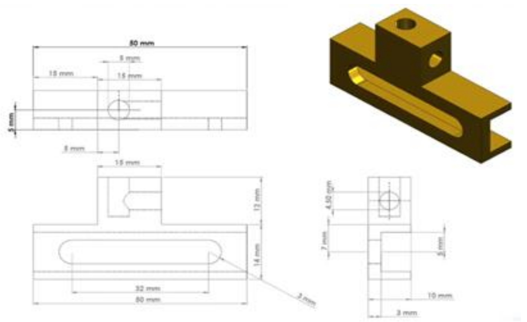

Fig-6: Cross Head

7. Crank Rod: Fig-7 shows the design view of crank rod. Crank rod is a part of piston engine which connects the piston to the crankshaft. It transfers the force of expanded air to crank shaft via a piston.

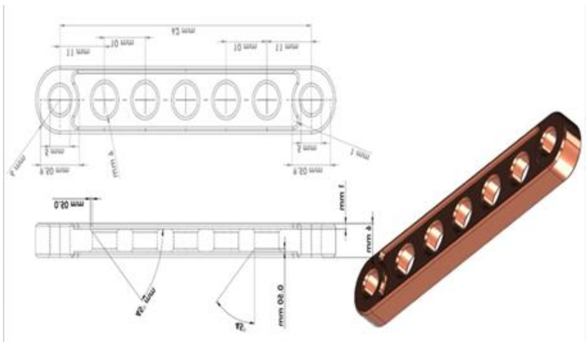

Fig-7: Crank Rod

8. Heat Exchanger Piston Tube: Fig-8 shows the design view of the heat exchange piston tube with diameter 35mm and length 87.50mm. This piston tube exchange heat from one body to another.

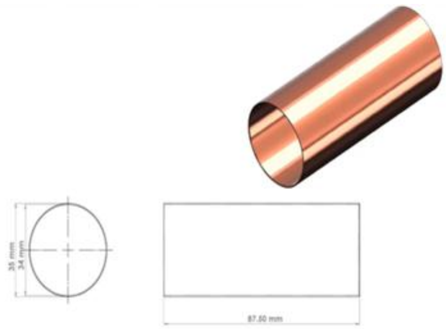

Fig-8: Heat Exchanger Piston Tube

9. Heat Exchange Cylinder: Fig-9 shows the design view of heat exchange cylinder. The cylinder has fins around it to exchange heat.

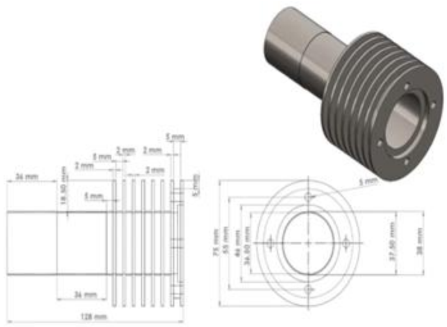

Fig-9: Heat Exchanger Cylinder

Fabrication:

Our project involved the design of a 90-degree Alpha Stirling engine using SolidWorks software, and all parts were designed in line with standard dimensions to fit together. The engine parts were manufactured utilizing CNC Machine techniques after they were designed using operations such as Machining, Milling, Lathe, Cutting, etc. In order to achieve good heat transfer, corrosion resistance and high ductile nature, we found copper as an ideal material for engine parts like heat exchanger piston head, crank rod and piston tube. During fabrication, rest of the parts were constructed using mild steel since it is inexpensive and weldable. Each hole was drilled with a drill machine, and the internal thread was dyed by hand using an iron. A surface finish improvement was achieved by treating all parts with emery paper following fabrication.

According to the standard dimensions for engine design, the theoretical calculations were done before fabrication in order to determine how much power the Stirling engine would produce. As a solar parabolic trough for concentrating solar energy was unavailable, we had to calculate power output with theoretical calculations and test the engine theoretically.

Fabricated Parts:

Fig-10: Cylinder

Fig-11: Crank Rod

Fig-12: Flywheel

Fig-13: Stirling Engine

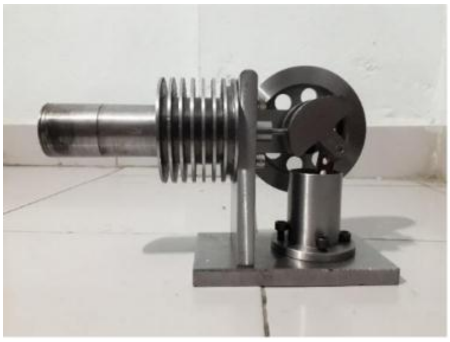

Fig -14: Stirling Engine

3. WORKING PROCEDURE

Solar Stirling engine process

- An engine starts when an external heat source, such as solar energy, 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.
- By expanding the gas, the piston is pushed away by the pressure, which starts the flywheel in motion.
- The power piston is linked with crank shaft and displacer piston is connected with crankshaft. As crankshaft moves the displacer piston drives to cold cylinder.
- 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.

4. 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

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

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

- Volume of air admitted

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

  $P_3 = 22.12 \times 10^6\ Pa$

- Heat supplied = $m \times C_v \times (T_2 - T_3)$

  $= 0.001 \times 0.707 \times (10547-500)$

  $= 0.39\ kJ/kg$

- 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 = $m \times C_v \times (T_1 - T_4)$

  $= 0.001 \times 0.707 \times (313 - 147.9)$

  $= 0.11\ kJ/kg$

- Work done = Heat Supplied – Heat Rejected

  $= 0.39 - 0.11 = 0.28\ kJ/kg$

- %Efficiency = (work done/Heat supplied)

  $= (0.28 \div 0.39) \times 100\ \% = 71.7\ \%$

- Performance calculation

  1) Area = $\pi \times D \times L$

     $= 3.14 \times 0.036 \times 0.124$

     $= 0.014\ m^2$

  2) Force = Pressure × Area

     Assume, P = 1 bar

     Force = $1 \times 10^5 \times 0.014$

     $= 1.4\ kN$

  3) Torque = Force × Radius

     Radius of flywheel = 18 mm

     $= 0.018\ m$

     Torque = 1.4×0.018

     $= 0.025\ kN\text{-}m$

  4) Power = $(2\pi \times N \times T) \div 60$ KW

     $= (2\pi \times 300 \times 0.025) \div 60$ KW

     $= 0.785\ kW$

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

5. RESULT

The results obtained from the theoretical calculations of the solar Stirling engine are discussed in this chapter. The Stirling engine was designed in SolidWorks with assumed dimensions. The designed parts were fabricated by performing CNC machining, CNC turning, drilling, wire cutting. 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 and fabricate the Stirling engine where design of the engine went well but, due to fabrication errors the engine is not working.

6. CONCLUSIONS

The following conclusions can be derived from the design and fabrication:

- The design of the Stirling engine provides the necessary data for the comparison of several aspects of the Stirling-cycle engine.
- The Stirling engine parts were fabricated according to dimensions in CNC machines.
- The theoretical efficiency is more than 70% for respective supplied heat.

REFERENCES

[1] B. Kongtragool, A review of solar-powered Stirling engines and low temperature differential Stirling engines, 2003, Vol. 7, pp. 131 – 154.

[2] Krissadang Sookramoon, Updraft gasifier-Stirling engine biomass incineration system power generation, 2022, vol 19, pp. 1-11.

[3] K. G. Maheswaran, Design and Manufacturing of Beta Stirling engine, 2017, vol 6, pp. 1-9.

[4] K. Dinesh, Design and Fabrication of low-cost Stirling engine, 2014, vol 3, pp. 75-78.

[5] Mohamed Abbas, Thermal performances of Stirling engine solar driven, 2008, vol 8, pp. 1-10.

[6] Muhammad Hassan, Design and Fabrication of Stirling engine for solar power application, 2021, vol 143, pp. 1-7.

[7] Najafi. G, Design, Fabrication and Evaluation of Gamma type Stirling engine, 2015, vol 7, pp. 137-143.

[8] Snyman. H, Design analysis methods for Stirling engines, 2008, vol 19, pp. 4-19.

[9] Vishal Gehlot, Development and Fabrication of Stirling engine, 2014, vol 11, pp. 69-71.

[10] Yaseen H. Mahmood, Fabrication of Stirling engine and study of its characteristics, 2018, vol 8, pp. 96-100.