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DESIGN FABRICATION AND PERFORMANCE STUDY OF A LOW TEMPERATURE DIFFERENTIAL STIRLING ENGINE

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Abstract- *A low temperature differential (LTD) Stirling Engine runs on low temperature differential (i.e. 80-100°C) which is very significant comparing to conventional Stirling Engine. Modified LTD Stirling engine has been recently introduced in application of alternative power generation and now is treated as one of the best means to recover waste heat energy. This research work outlines the design, fabrication and performance of a LTD Stirling Engine using low temperature differential. The main objective of this research is to make a feasible study and finally operate such engine at a very low temperature difference. The performance is carried out between the temperature difference 71 and 91°C. It is found that the maximum efficiency is 24.52% when the engine is running at 74 rpm. This paper also shows the Stirling Engine in combination with renewable sources can be a part of sustainable energy supply.*

Keywords: LTD Stirling Engine, Efficiency, Power Generation

1. INTRODUCTION

A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work [1]. The engine is like a steam engine in that all of the engines heat flows in and out through the engine wall. This is traditionally known as an external combustion engine in contrast to an internal combustion engine where the heat input is by combustion of a fuel within the body of the working fluid. Unlike the steam engine's use of water in both its liquid and gaseous phases as the working fluid, the Stirling engine encloses a fixed quantity of permanently gaseous fluid such as air or helium. As in all heat engines, the general cycle consists of compressing cool gas, heating the gas, expanding the hot gas, and finally cooling the gas before repeating the cycle [2]. Another prime advantage of the LTD Stirling engine is less expensive and easy to construct [3]. There are different types of Stirling Engine available at present. But in this project; a complex demonstrated [4] twin cylinder LTD Striling Engine is locally fabricated with a new approach and configuration. Analysis is carried out to find the engine performance and prospect of using low temperature waste heat source. The significant features of this engine compare to conventional Stirling Engine is, it can operate at a very low temperature difference around 80-100°C which cannot possible for conventional engine to run at such low temperature difference .So is can be considered as a special type and highly prospective engine to convert low temperature heat into work. The main objective of this research is to make a feasible study and finally operate such engine at a very low temperature difference.

2. THEORY AND OPERATING PRINCIPLE

The idealized Stirling cycle consists of four thermodynamic processes acting on the working fluid:
First of all the isothermal expansion that means expansion-space and associated heat exchanger are maintained at a constant high temperature, and the gas undergoes near-isothermal expansion absorbing heat from the hot source. Secondly the constant-volume (known as iso volumetric or isochoric) heat-removal- The gas is passed through the regenerator, where it cools transferring heat to the regenerator for use in the next cycle. Thirdly, isothermal compression. In the stage compression space and associated heat exchanger are maintained at a constant low temperature so the gas undergoes near-isothermal compression rejecting heat to the cold sink. Finally the constant volume heat-addition (known as iso volumetric or isochoric) heat addition. The gas passes back through the regenerator where it recovers much of the heat transferred in 2 to 3, heating up on its way to the expansion space. The operating principle and the thermodynamic cycle of the conventional Stirling Engine and this LTD Stirling Engine are just as same. The thermodynamic cycle of the engine is shown bellows figure no. 1.

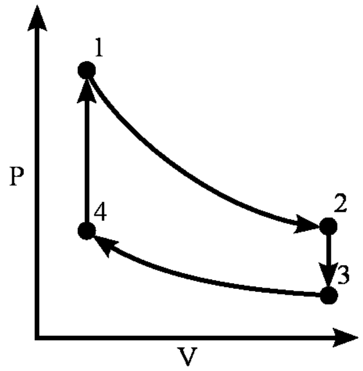

Fig 1: P-V diagram

While discussing the ideal Stirling process, we assumed isothermal processes. But to ensure such a process, it has to go infinitesimally slowly to always ensure equilibrium of temperature. When building an engine it is difficult to realize the isochor processes while at the same time having an evenly running system. So in every Stirling engine built, the different steps are not separated strictly but overlap each-other. This is shown in the following Fig. 2.

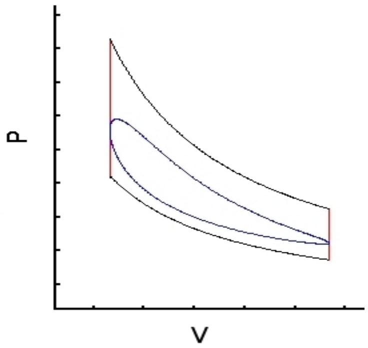

Fig 2: Ideal Stirling process P-V diagram

The thermal efficiency of LTD Stirling Engine is considered equal to the thermal efficiency of hypothetical Carnot cycle - i.e. the highest efficiency attainable by this heat engine. But in practical it was not happened for this experiment. The thermal efficiency can be calculated from the following equation. Here T_c and T_h indicates cold and hot surface temperature of displacer plates respectively.

$$\text{Thermal Efficiency} = \frac{T_h - T_c}{T_h}$$

3. BASIC CONSTRUCTION

There are total 21 parts of this locally fabricated model engine. These are- Top plate, bottom plate, Displacer piston, Chamber Ring, Flywheel, Flywheel Housing, Flywheel Stand, Flywheel Hub, Bearing Collar, Cylinder, Piston, Cylinder Base, Piston Yolk, Displacer Gland, Gland Rod, Crank Shaft, Displacer Rod, Bearing Collar, Bearing Ring, Displacer Connecting Rod, Piston Connecting Rod and Prototype. All the parts are scaled downed and redesigned with a new approach base on a demonstrated Stirling Engine [4]. All the parts are made of aluminum except the displacer piston. It is made of Styrofoam. The displace cylinder is made of fiber plastic and the O ring is used for selling purpose is a special type gasket.

4. DESIGN OF 3D PARTS

All parts of locally fabricated LTD Stirling Engineare shown in Fig. 3 and Fig. 4.

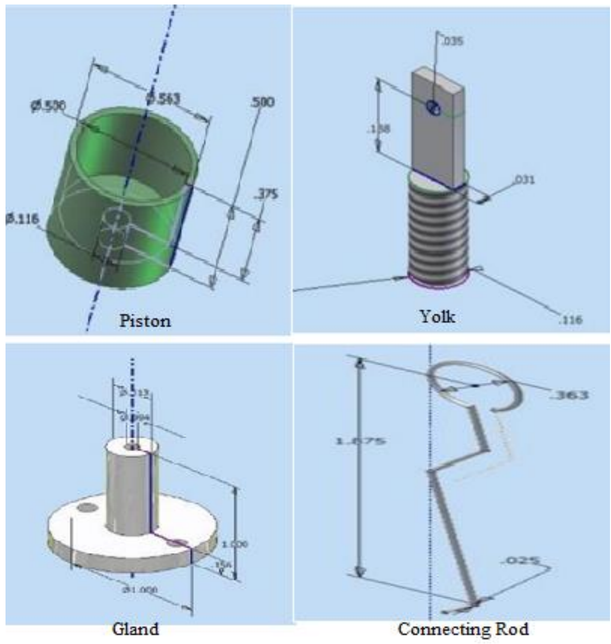

Fig. 3: Piston and displacer

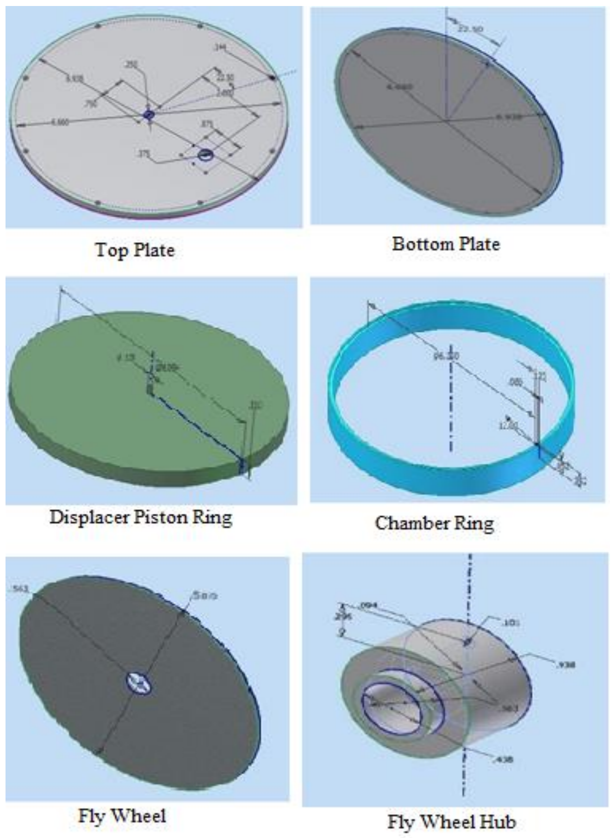

Fig. 4: Different plates, rings and fly wheel

Figure 5 represents front and side views of the prototype after assembling all its parts.

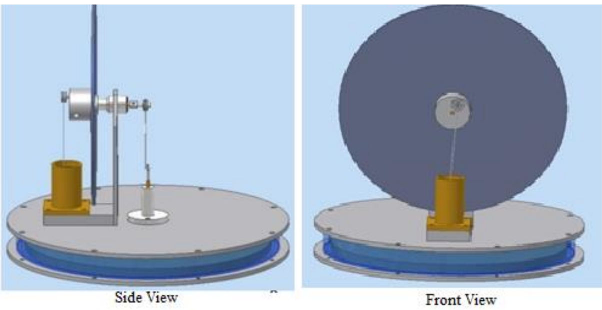

Fig. 5: Prototype of the LTD Stirling Engine

5. FABRICATION AND FINAL ASSEMBLY

After manufacturing all parts individually the final assembly of engine is done as shown in Fig.4 Material that is used for fabrication of engine component is mostly aluminum as because of its light weight and easy machining. Components are fabricated as per design using local lathe machine. Styrofoam is use as a displacer chamber and fiber plastic is used as a displace cylinder. Displacer cylinder is grooved both on top and bottom side for putting O rings. The fly wheel stand, the piston, the displacer piston are attached with the top plate. Before attaching the flywheel stand the flywheel housing is put into the stand hole. Total nine holes are made on the fly wheel just for balancing purpose. Secondly, bearings are attached to the two end of the housing to hold the crankshaft. At the two end of the crankshaft flywheel hubs are attached. Then, one end of the both connecting rods is joined into the two hubs and other end of the connecting rod is attached with the displacer piston and the power piston. Finally, the displacer chamber is set between two plates and it is joined by screws. This setup is then investigated for numerous observations to determine its efficiency without load and with load.

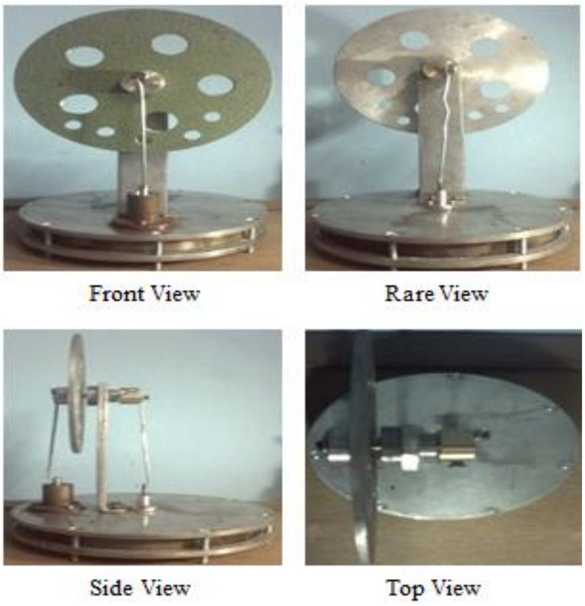

Fig.6: Fabricated LTD Stirling Engine

6. PERFORMANCE ANALYSIS

The manufactured LTD Stirling engine is carried out for numerous investigation to find out the efficiency. The findings from the engine are shown in Table I to Table IV. Performance is analyzed by applying and without applying load. For applying load, a plastic gear is attached at the rare side of the flywheel and meshed with another plastic gear which is attached at one end of the shaft of a 5 watt DC generator. The efficiency is calculated based on the Carnot equation.

Table 1: Performance Data without Load

Observation No.	Temperature of hot pale (°C)	Temperature of cold pale (°C)	Temperature difference	R.P.M.
1.	80	7	73	69
2.	84	7	77	74
3.	89	7	82	87
4.	93	7	86	94
5.	98	7	91	107

Table 2: Performance Data with Load

Observation No.	Temperature of hot pale (°C)	Temperature of cold pale (°C)	Temperature difference	R.P.M.
1.	78	7	71	61
2.	86	7	79	63
3.	91	7	86	67
4.	94	7	87	71
5.	98	7	91	74

Table 3: Efficiency without Load

Temperature difference (°C)	Efficiency (%)	R.P.M.
73	20.68	61
77	21.56	63
82	22.65	67
86	23.49	71
91	24.52	74

Table 4: Efficiency with Load

Temperature difference (°C)	Efficiency (%)	R.P.M.
71	20.23	61
79	22.00	63
86	23.63	67
87	23.80	71
91	24.52	74

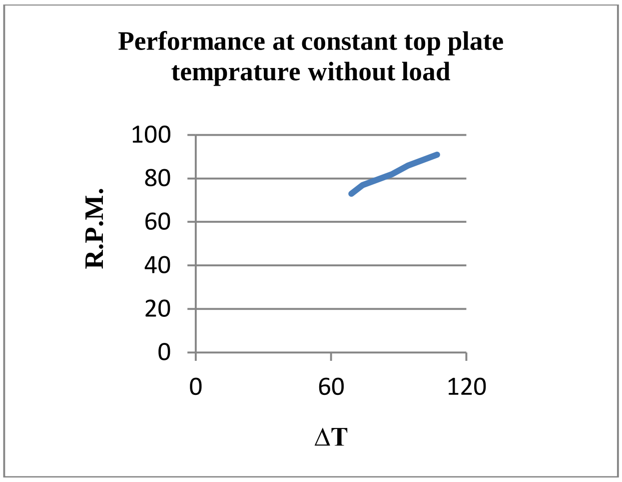

Fig. 7: Temperature vs. speed curve (without load)

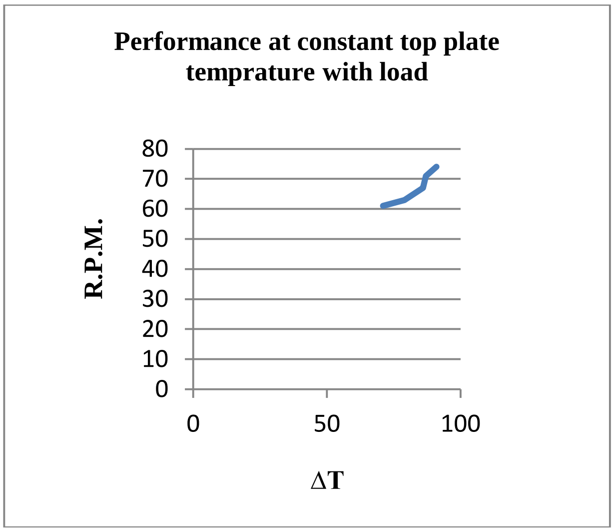

Fig. 8: Temperature vs. speed curve (with load)

From the above Table 1 to Table 4 and Fig. 7 to Fig. 8, it is found that the engine speed is increased with increase of temperature difference. The efficiency of engine is also increased with increase of temperature difference in case of both without load and with load.

7. CONCLUSIONS

The LTD Stirling engine is designed and fabricated to carry out its performance. This LTD Stirling Engine operates between 71°C and 91°C, which is very smaller temperature difference compared to conventional Stirling engine. The maximum efficiency of this LTD Stirling engine is 24.52 % which is close to efficiency of conventional Stirling engine (27%). There is a significant change of R.P.M. with the change of temperature difference and it is efficient to recover waste heat from the low temperature heat sources.

8. REFERENCES

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