Design Modifications of Alpha Stirling Engine for Reducing the Cylinder Pressure Loss and the Blow-By

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Abstract— This work focuses on a new approach to design a Stirling engines with the goal of building a working model. This Alfa type Stirling engine had two kinetic luna engines, one is used as hot expansion cylinder and another as cooled compression cylinder. Both the cylinders are connected by – using crank pin to link the two connecting rods with the crank shaft and by using pressure pipe with heat exchanger to connect the two heads. Alpha stirling engine has high power to volume ratio but it has technical problems due to high temperature, the durability of its seals get reduced. In this, the regenerator is an internal heat exchanger and temporary heat is stored in between the hot and cold spaces such that the working fluid passes through it first in one direction then in reverse direction. The compression ratio of the engine is calculated analytically and the pressure is measured by using pressure gauge. The design of the engine is modified and the leakages at the joints and blow-by are detected and are reduced.

Key words: Stirling Engine, Blow by Effect, Compression Ratio, Lubricating Oil, Sealing Effect

I. INTRODUCTION

The Stirling Engine is hot air engines. It was invented by Robert Stirling (1790-1878) and his brother James. The ideal Stirling thermodynamic cycle, the efficiency of a frictionless Stirling engine would be the same as that of a Carnot cycle engine, i.e, the maximum theoretically efficiency attainable in any heat engine. But it was only in 1953, with the invention of rhombic drive, that the Stirling engine has developed to a stage competitive to diesel and petrol engines.

Stirling engine is external combustion engines that uses air or other gases as working fluid. It uses solid or liquid fuel as its heat source. Heat transfers through the engine wall or a heat exchanger. The fluid then, expands and produces motion in the engine. The fluid is then cooled, compressed and reused (closed cycle), or dumped, and cool fluid pulled in (open cycle air engine). It operates by shuttling a compressed gas between two chambers separated by a lightweight piston. The engine cycle thrusts using the transport of heat across a constant temperature difference on both side of the chamber. It operates by cyclic compression and expansion of air or other gas [5].

There are three main types of stirling engines:

- Alpha type, Beta type and gamma type

Stirling cycle: It is a closed and reversible cycle.
Processes involved:

- 2: isothermal compression
- 3: isochoric heat addition
- 4: isothermal expansion
- 1: isochoric heat rejection

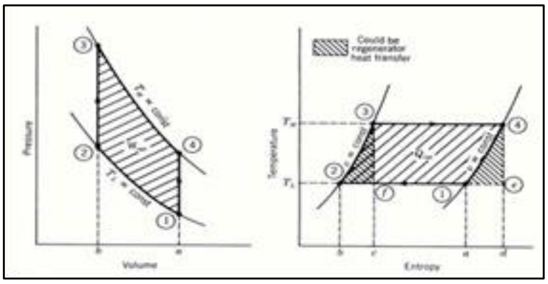

Fig. 1: Stirling cycle

In an alpha stirling engine, there is separate the hot and cold chambers, usually in separate cylinders. Hot chamber is for expansion and cold chamber is for compression. The connecting rods are linked to the same crankshaft. The two piston volumes are linked through a pipe with the regenerator placed in the path of the fluid between them.

A. Blow-by Effect[4]

During a combustion or compression in the cylinder, the gas that enters the crankcase is called blow-by. On the piston, the piston rings is mounted as the sliding closure of the cylinder. There is always a small amount of clearance left between the piston, rings and wall, even despite of accurate construction which cause some leakage to the crankcase.

The parameters on which the amount of Blow-by gases generated in the cylinder depends upon engine load, engine speed, break mean effective pressure. But there are few other like wear of components which is extremely difficult to measure as this is a time taking process to analyze the amount wear and which component is wearing. Amount of Blow-by is directly dependent on the amount of wear, as the wear of the piston or the piston rings increases the amount flue gas leakagealso increases in the crankcase. These flue gases also causes harm to the parts in the crankcase by increasing temperature of the lubricating oil in the crankcase, which changes the property of the oil[1].

II. EXPERIMENTAL WORK

In this work firstly, we have completed the assembling of the engine from its initial state and have observed the pressure of the engine in the assembly and at the heads individually by using pressure gauge. The pressure is also measured with different lubricating oils (such as 32 turbine oil, 10W40 engine oil, 75W90 gear oil and grease)

Initial cranking to the engine is given by:

- Hand cranking.
- Coupling the pulley of the engine with the motor's pulley using v-belt for providing initial torque.

Leakage testing of the engine at the joints using soap water, using metal filler as sealant at the joints, to make it leak proof.

Modification in the design of the engine by reducing clearance volume.

Name of the Parts	and its Specification
Cylinder diameter	3.84cm
Stoke length	4.3cm
No. of cylinders	2
Pressure pipe diameter	0.6cm
Pipe length	65cm
Standard compression ratio	8
Connecting rod length	8.8cm
Crank radius	2.15cm
Modified pipe length	36cm
Electric heater	750Watt

Table 1: Parts Specification of the engine

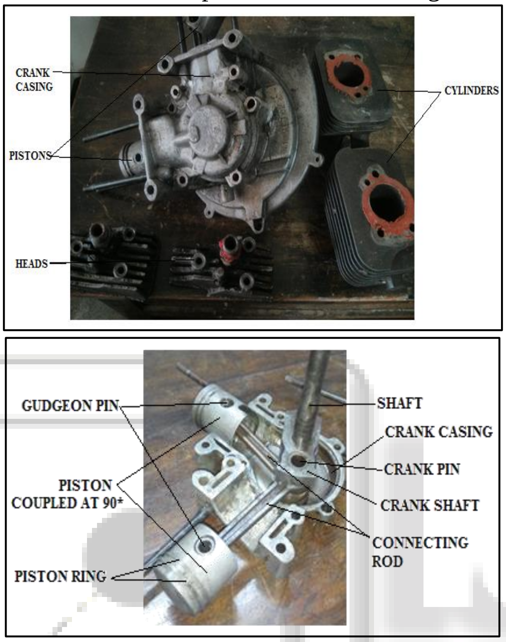

Fig. 2: Initial State of the Engine

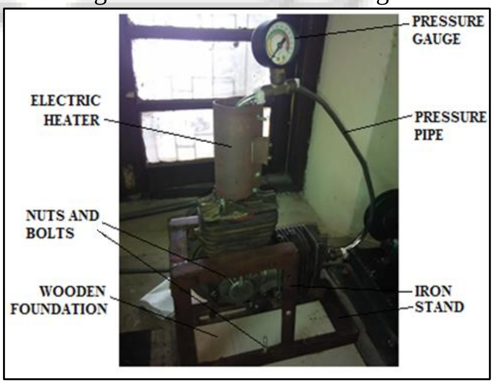

Fig. 3: Assembled Engine

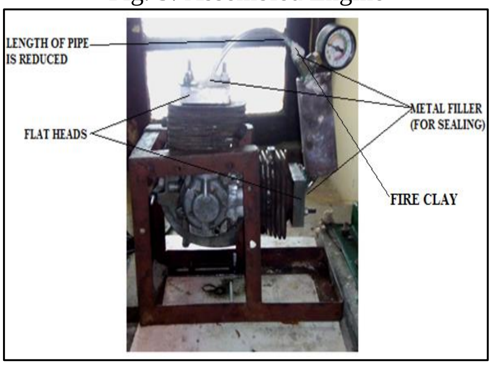

Fig. 4: Modified Engine

III. EXPERIMENT PROCEDURE

1) From initial state, disassemble the engine, clean each part using kerosene and lubricate them using oil.
2) Provide proper lubrication between cylinder and piston and then, use gasket maker for providing sealing between the heads and the cylinders.
3) Use cylindrical electric heater of 750W on the heat exchanger as a heating source.
4) Connect the two cylinder heads using pressure pipe with a regenerative heat exchanger and pressure gauge on one of the heads (hot cylinder).
5) Set the engine on the iron stand for support and then tighten the stand on the wooden foundation using nuts and bolts.
6) Leakage testing and its reduction by using soap water and measuring pressure in assembly and at heads with different lubricants
7) First trial, after assembling the engine, the heater is switched on and after 20 minutes, it reached a temperature of 450 °C and the temperature of heat exchanger reaches 350 °C, which is measured by using infrared thermometer gun. Then giving initial cranking to the engine.
8) Modification in the design of the engine by reducing the length of the pipe and replacing the oval heads with the flat heads.
9) Again, leakage testing and taking second trial of the modified engine.

IV. RESULTS AND DISCUSSION

A. Measured the pressure developed in the assembly and at the two of the individual heads using pressure gauge with different lubricating oil

Cases (type of lubricant)	Position of pressure gauge	
	In the assembly near heat ex- changer	
	Pressure with-out Heat supply (kg/cm^2)	Pressure with Heat supply (kg/cm^2)
– For boundary lubrication using turbine oil	0.2	0.32
– For thick film lubrication using turbine oil	0.3	0.4
– For thick film lubrication using engine oil	0.36	0.48
– For thick film lubrication using gear oil	0.4	0.53
– For mixture of gear oil and grease	0.4	0.53
Cases (type of lubricant)	At heads (individually)	
	Pressure at Hot head (kg/cm^2)	Pressure at Cold head (kg/cm^2)
For boundary lubrication using turbine oil	2.2	3

– For thick film lubrication using turbine oil	2.6	3.4
– For thick film lubrication using engine oil	3	3.8
– For thick film lubrication using gear oil	3.8	4
– For mixture of gear oil and grease	3.8	4

Table 2: Pressure readings for different lubricant

– Charts for the above tables

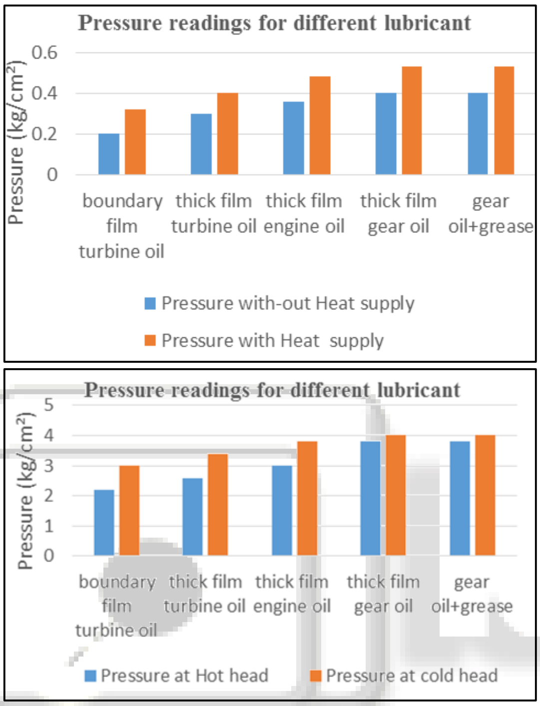

Fig. 5: Charts

B. Table for modified engine

Cases (type of lubricant)	Position of pressure gauge: In the assembly near heat ex-changer	
	Pressure without Heat supply (kg/cm²)	Pressure with Heat supply (kg/cm²)
– For boundary lubrication using turbine oil	0.24	0.37
– For thick film lubrication using turbine oil	0.34	0.45
– For thick film lubrication using engine oil	0.4	0.53
– For thick film lubrication using gear oil	0.44	0.58
– For mixture of gear oil and grease	0.44	0.58

Table 3: Pressure readings for different lubricant

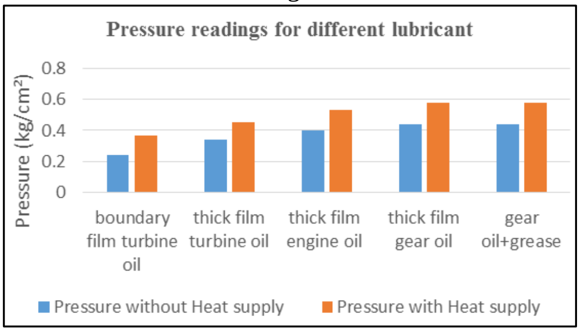

Fig. 6: Chart

C. The % increse in the pressure readings in the assembly with heat supplied of the two models

Pressure for the first model of the engine= 0.53kg/cm²

Pressure for the second model (improved design) of the engine= 0.58 kg/cm² = 0.58 - 0.53 = 0.05 kg/cm²

Therefore % increased = $\frac{0.05}{0.53} \times 100 = 9.43\%$

D. Calculation of compression ratio of the two models of the engine

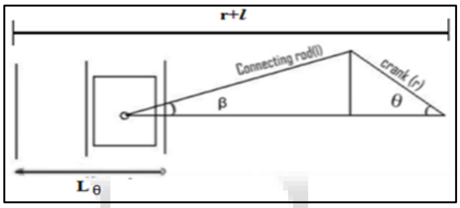

Fig. 7: Connecting rod and crank shaft

From fig 7, we have

Stroke length: $L_\theta = (l + r) - l\cos\beta - r\cos\theta = l\,(1-\cos\beta) + r\,(1-\cos\theta)$

$r\sin\theta = l\sin\beta$

Then,

$$\beta = \sin^{-1}\left(\frac{r}{l}\sin\theta\right)$$

Total volume = $\frac{\pi}{4} D^2 L\theta$ + Clearance volume

Clearance volume v_c= volume of pipe + clearance volume of the cylinders.

= cross section area of pipe × length of pipe + $\frac{\text{swept volume} \times n}{\text{compression ratio} - 1}$

$$v_c = \frac{\pi}{4} dp^2 lp + \frac{\frac{\pi}{4} D^2 L\theta \times n}{rst - 1}$$

Therefore clearance volume = $\frac{\pi}{4} \times 0.6^2 \times 65 + \frac{\frac{\pi}{4} \times 3.84^2 \times 4.3 \times 2}{8-1} = 32.60689\text{cm}^3$

Compression ratio = $\frac{\text{Maximum total volume}}{\text{minimum total volume}} = \frac{\text{maximum swept volume} + \text{clearance volume}}{\text{minimum swept volume} + \text{clearance volume}}$

Maximum and minimum value of total volume is attained by the engine at θequal to 135 and 315 respectively

θ	β	Strok e lengt	Swept volum e	Swept volum e	Cleara nce volum	Total volum e
13	9.948	3.802	44.03	44.03	32.606	120.683
31	-	0.762	8.825	8.825	32.606	50.257

Table 4: Crank angle and Total volume

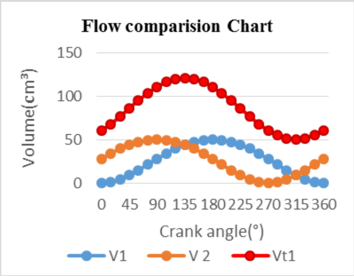

Fig. 8: Chart

$$\text{Compression ratio} = \frac{\text{maximum volume}}{\text{minimum volume}} = \frac{120.6838}{50.25741} = 2.4$$

1) For Modified Engine

Length of pipe is reduced to = 36cm

Clearance volume of the cylinder for replaced oval head with the flat plate = 5.86cm^3

(Measured using water and measuring jar)

$$\text{Therefore clearance volume} = \frac{\pi}{4} \times 0.6^2 \times 36 + 2 \times 5.86 = 21.9\text{cm}^3$$

θ	β	Stroke length (L) cm	Swept volume (V1)cm^3	Swept volume (V2)cm^3	Clearance volume (Vc)cm^3	Total volume (Vt)cm^3
135	9.94827	3.80259	44.03843	44.03843	21.9	109.9769
315	-9.94827	0.762036	8.82526	8.82526	21.9	39.55052

Table 5: Crank angle and Total volume

$$\text{Compression ratio} = \frac{\text{maximum volume}}{\text{minimum volume}} = \frac{109.9769}{39.55052} = 2.78$$

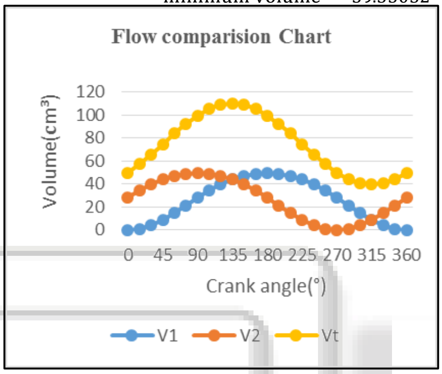

Fig. 9: Chart

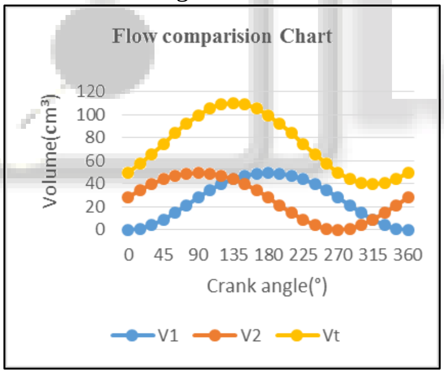

Fig. 10: Chart

- The increased % of compression ratios of the two models

Compression ratios for the first model of the engine= 2.4

Compression ratios for the second model (improved design) of the engine= 2.78 = 2.78 - 2.4 = 0.38

$$\text{Therefore \% increased} = \frac{0.38}{2.4} \times 100 = 15.83\%$$

V. CONCLUSION

- Blow-by is the main reason for not working of the engine as we have observed that there is improvement in the pressure readings for the thick layer lubrication of the high grade oils, at the cylinder heads.
- The second reason could also be friction, as the engine did not work even with the improved pressure readings and for the improved design.
- Thirdly, the engine could be of high capacity (i.e.100cc) and we are not able to generate the required amount of pressure to run it.
- There is increase in the pressure of the engine by 9.43% and increase in compression ratio by 15.83% with the modification in the engine.

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