Design And Fabrication Of Low Cost Stirling Engine For Low Duty Industrial Applications

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Abstract: In recent year's usage of energy is very high. Researches are being done to find alternative sources for energy. There are many ways by which modifying existing techniques will help to reduce the usage. The paper proposes the way to build and utilize the low cost Stirling engine for the green energy applications. The research on Stirling engine is being increased, many inventions reveals the suitability of engine for low power applications that includes an alternative for motors in industries. As it knows that Stirling engine has closer theoretical Carnot cycle efficiency. This theoretical efficiency of engine provides an alternative for various industrial low duty applications. Finally this paper will outline theoretical background of Stirling cycle; various design parameters, innovative use of fabrication works and industrial implementation ways. The design process involves the design of cylinders, its mass flow rate, amount of heat addition, heat rejection, efficiency and many more. These sub design parameters helps in finding out power outcome of the engine. The fabricated work involves usage of available materials in and around effectively. As a result final assembly of the engine meets the objective.

Index Terms: Design, Manufacturing, Material selection, further scope, Industrial applications, Cost.

1 Introduction

Stirling engine is an external combustion heat engine where heat is provided outside the cylinder. It operates by continuous cyclic compression and expansion of air or any other gas, the working fluid, is subjected to different temperature levels so that there is a net conversion of heat energy to mechanical work. In this type of engine the working fluid is constantly held inside the cylinder. Which means the system is in thermal equilibrium. Stirling engine is distinct from other heat engines by means of regenerator through which hot gases moves from one chamber to another chamber. The main advantage of Stirling engine is that it can operate with any heat source. The efficiency of this heat engine is very high when compared to any other heat engine.

2 OVER VIEW OF STIRLING ENGINE



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Ideal Stirling engine is based on Stirling cycle which is shown in above figure. The following are the process that are involved in Stirling cycle

Process 1- 2: Isothermal compression At constant temperature air (working fluid) is compressed Q (1-2) =area 1-2-b-a on T-s diagram Work is done on the working fluid W (1-2) =area 1-2-b-a on P-v diagram.

Process 2- 3: Isochoric heat addition At constant volume heat is added to the hot cylinder Q (2-3) = area 2-3-c-b on T-s diagram Work done [W (2-3)] is zero

Process 3- 4: Isothermal expansion At constant temperature working fluid is expanded Q (3-4) = area 3-4-d-c on T-s diagram Hot air expands Work is done by the working fluid W (3-4) = area 3-4-a-b on P-v diagram

Process 4- 1: Isochoric heat rejection Heat is rejected at constant volume. Q (4-1) = area 1-4-d-a on T-s diagram Work done [W (4-1)] is zero

3 DESIGN SELECTION

Design concept	Various design criteria					
	Power output	simpli city	Literature availability	η	losses	aestheti cs
Gamma type	2	2	1	3	3	3
Rotary stirling	3	1	3	3	1	3
Inline alpha stirling engine	1	2	2	1	2	1

There are 3 different types in which stirling engine can be design and fabricated. From the previous inventions the following table has been laid out by having 'types of designs' along 'Y' axis and 'various parameters' along 'X' axis. This survey is made in order to ensure the best design chosen and the design selection process evaluated are to be excellent and simpler the categories include friction losses, simplicity, available literature, temperature differential, efficiency, and aesthetics.

1-Excellent, 2-Moderate, 3-Poor

Hence by the above table it is been proved that inline alpha engine has greater feasibility ratio compared to other types.

4 Design of Engine Components....

The following are the sub-assemblies that are required either to search a component of similar dimensions or to fabricate.

4.1 Design of frame

The frame is used to support piston cylinders, flywheel connected shaft and other rotating parts. The frame was constructed using aluminium plate which is easier to machine and light weight. Frame is bought to its shape with the help of lathe and circular holes are drilled by means of drilling machines. Bearings are provided inside the supports to hold horizontal shaft.

4.2 Design of piston

The piston can be constructed of cold rolled steel to ensure its thermal properties for the hot cylinder assembly. This plays an important role as in case of tolerances between the piston and cylinder walls. To have a greater efficiency the surface finish should be very high so that losses will be minimum, but due to machining complication it's good to buy a machined product which suits the design requirements.

4.3 Design of cylinders

Two cylinders (Hot and cold chambers) are of same dimension. It can be fabricated using cold forging or casting. Due to high surface finish criteria it is forged then finishing operation is done through internal grinders. Aesthetics an external combustion engine the material selection plays a vital role

4.3.1 Material selection

Among the materials listed copper has high melting point and thermal conductivity which is essential for engine and also the thermal expansion of copper is less so the engine can be operated at high temperature for long time. But the material cost is too high and hardness is low compared to other materials In aluminium the thermal conductivity is high, weight is less but material strength is less compared to copper. Thermal expansion is high so it cannot be operated for long time at high temperatures. In stainless steel oxidation resistance is high compared to other materials also it has better strength compared to aluminum but the cost of the material is very high.

Propert ies - Material	Mel ting Point (K)	Thermal Conductiv ity (W⋅m ⁻¹ ⋅K ⁻¹	Therm al Expansion n (μm·m ⁻¹ ·K ⁻¹⁾	Brinn el Hardn ess	Oxidation resistance
Alumini um	933	237	23.1	67	Medium
Stainles s Steel	240 0	19	17	110	High
Cast Iron	126 0	60	10.8	415	Poor
Copper	135 7	401	16.5	85	High
Mild Steel	260 0	147	14	130	Moderat e

The gray cast iron has high strength cost of the material is also low but it has low thermal conductivity and low melting point so it cannot withstand high temperature for long time The material we chose is mild steel even though thermal conductivity is lesser it is slightly near to the copper and the thermal expansion is lesser when compared to aluminium.it also has high melting point, cost of the mild steel also less compared to copper the main disadvantage of using mild steel is that it reacts with atmospheric air so it readily under goes oxidation reaction. This can be protected by applying chromium coat over the metal surface. This also increases conductivity of the material.

4.4 Design of piston

As Stirling engine is an external heat engine. The heat source that is to be supplied also plays a role. Heat can be from sun (solar energy), Industrial wastages through fittings, geothermal energy, nuclear wastes. A recent development which includes trapping of solar energy using micro is also a way to generate heat from sun.

5 DESIGN CALCULATIONS

Swept volume= $(\pi/4*D^{2*}L) = (\pi/4*0.056*.14025)$ = 349.45*10⁻⁶ m³

Clearance volume = 5% of swept volume = $5^{349.45^{10^{-6}}}$ V₂= 17.47^{10^{-6}} m³

Volume of air admitted (V₁) = Swept + Clearance V₁=349.45*10⁻⁶ m³+17.47*10⁻⁶ m³

= 366.92*10⁻⁶

Compression ratio (r) = $V_1/V_2 = (366.92^*10^{-6} / 17.47^*10^{-6})$ = 21.005

1-2 isentropic process

 $T_2/T_1 = (V_1/V_2) \land (Y^{-1})$ = (366.92*10⁻⁶ / 17.47*10⁻⁶) \land (1.4-1) = **994 K**

According to ideal gas equation $P_1V_1 = mRT_1$

Mass of air (m) =0.001kg, Temperature of air = 300K $P_1^*366.92^*10^{-6}$ =0.001*0.287*300 $P_1 = 0.23^*10^6$ kPa

$$\begin{split} P_2/P_1 &= (1/r \texttt{Y}) \\ P_2 &= 1/\ (21^{1.4})^* (0.23^* 10^6) = \textbf{3.24}^* \ \textbf{10}^6 \ \textbf{Pa} \end{split}$$

2-3 Constant Volume Process $V_3 = V_2$

 $P_{3}*V_{3} = mrT_{3}$

 $\begin{array}{l} P_3 * 17.47 * 10^{-6} = 0.001 * 0.287 \\ P_3 = 25.02 * 10^6 \end{array}$

Supply Heat temperature (T₃) =1523 K

Heat supplied = $m^*Cv^*(T_3-T_2) = 0.001^*0.707^*(1523-994.7)$ = 0.43 kJ/Kg

3-4 isentropic process

 $P_3/P_4 = rY$ $P_4 = 1*25.02*10^6/(21^{1.4}) = 35.2*10^4 Pa$

4-1 Constant volume process $T_4 / T_1 = P_4 / P_1$ =(35.2*10⁴/0.23*10⁶)*300 =459.13K

Heat Rejected = $m^*Cv^*(T_4-T_1)$ =0.001*0.707*(459.13-300) =0.2 kJ/Kg

Work done = Heat Supplied – Heat Rejected = 0.22 kJ/Kg

%Efficiency = (work done/Heat supplied) = (0.22/0.42)*100 =**52.3%**

Performance calculation

 $\begin{array}{l} Power = 2\pi NT/60 \ \text{KW} \\ \hline \text{Torque} = \text{Force} * \text{Radius} \\ \hline \text{Force} = \text{Pressure} * \text{Area} \\ \hline \text{Area} = \pi^* D^* L = 3.14 * 56.25 * 140.625 = 0.0248 \text{m}^2 \\ \hline \text{Pressure} = 2 \ \text{bar} \\ \hline \text{Force} = 2 * 10^{\circ} 5 * 0.0248 = 4.923 \ \text{KN} \\ \hline \text{Torque} = 4.923 * 0.035 = \textbf{0.172} \ \text{KN-m} \\ \hline \textbf{Power} = (2 * \pi * 200 * 0.172)/60 == \textbf{3.6} \ \text{KW}. \end{array}$

6 FABRICATION TECHNIQUE

The fittings used to connect the pistons and cranks were made of Mild Steel due to its moderate sliding frictional properties. In fabrication, complication of connecting rod and crank are overcome by our innovative techniques. Also the aim is to reduce the cost by the usage of existing product, so we chose TVS 50 crank and connecting rod. A slight modification was made on the rod fittings. The length of the piece should be 140mm as per our design but size of the TVS 50 connection rod is 105mm. As a result the original connecting rod length was extended to 140mm by choosing same kind of material which is cut and welded in between big and small end of connecting rod. The design of the cranks had to incorporate the generation of a force couple for output power, and that should cancel the linear translational force exerted on the system due to the mass of the piston accelerating over its stroke length. The crank and the crank shaft weight ratio was sketchy. So we chose TVS 50 Crank. The two cranks are joined by welding and bearings are attached at both ends of the shafts. Hence our fabricated model looks



7 FURTHER SCOPE

The output of the engine is less than what is been expected it can be further increased by following ways. To increase the efficiency fins are provided over the cylinder so the heat transfer rate will be high when compared to normal cylinders By operating at various temperatures we can obtain various efficiencies. Also Stirling engine can utilize the power of the sun to provide the necessary energy to the system with the help of micro controllers. The main purpose of the project served to promote the use of Stirling engines in 'green energy' applications. Due to the high theoretical efficiencies of Stirling engines they are a prime candidate for future solar energy generation research. Solar powered Stirling engines are now commercially available up to 25 kW of generating capacity.

8 IMPLEMENTATION OF STIRLING ENGINE FOR INDUSTRIAL PROBLEMS

Stirling engines can run directly on any available heat source, not just one produced by combustion, so they can run on heat from solar, geothermal, biological, nuclear sources or waste heat from industrial processes.

- 1. Electricity production: By coupling the dynamo with Stirling engine, above mentioned heat source engine is made to run and electricity is produced
- 2. Alternate for motors: In industries, instead of using motors the pumps, compressors and low power machines are directly run with the help of Stirling engine by utilizing waste heat.
- 3. Dual power output to increase engine performance: Waste heat is easily harvested (compared to waste heat from an internal combustion engine) making

Stirling engines useful for dual-output heat and power systems.

- 4. Fuel saver: Like Petrol-Battery hybrid cars, Petrol-Stirling or diesel-Stirling hybrid vehicles can be used
- Increase in engine efficiency: Stirling engine are used in automobiles to operate Air conditioning and various pumps. So we can increase the main engine efficiency
- 6. Alternate for Air conditioner: engine is extremely flexible which can be used as CHP(combined heat and Power) in winters and as coolers in summer

9 COST ESTIMATION

S.N O	PART	MATERIAL	QUANTITY	COST (INDIAN RUPEES)
1	Hot Cylinder	Mild steel	1	200
2	Cold Cylinder	Mild steel	1	200
3	Piston	Aluminium	2	300
4	Transfer tube	Mild steel	1 ft	60
5	clamp	Iron	2	120
6	Frame	Aluminium	1	350
7	Bearing	Stainless steel	2	40
8	Crank with shaft	Cast iron	2	730
9	Connectin g rod	steel	2	550
10	Fly wheel	Cast iron	1 (0.7kg)	80
11	Machining cost(India)	-	-	900
12	Total	-	-	3530

10 CONCLUSION

Even though output of engine is not sufficient to run a entire vehicle but it can be used as secondary engine in automobiles, and for all industrial light duty operations. Hence the objective of designing and manufacturing of engine was successful and can be implemented as a replacement to low power motors. It's been proved that running cost of the engine is also very less this will help to minimize the usage of fuel and reduce air pollution

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