Design and Fabrication of Solar Stirling Engine

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***Abstract*— In the present scenario the need is clean and green energy based on the renewable energy resources. The solar energy is one of the cleaner and greener energy available in abundance. The stirling engine in combination with solar concentrator is a very efficient and clean source of energy, thereby provides us an answer to the problem of cleaner and greener energy. This report presents different components and its various configurations along with the feasibility of using solar energy as a potential source of heat for deriving a Stirling engine. There is design and calculations of different components of solar Stirling engine.**

Keywords—Stirling engine; Solar energy; Auto CAD;CATIA

I. INTRODUCTION

Due to environmental factors, the entire world is looking for alternative energy sources. For decades scientists have been researching everything from photovoltaic cells to solar troughs in an effort to find ways to use clean, renewable resources to generate power. Many of these breakthroughs can be expensive and difficult to maintain for such little power output compared with traditional power generation. Finally, an invention that is over 100 years old may provide a solution – the Stirling engine combined with solar power.

The Stirling engine in combination with solar concentrator is a very efficient and clean source of energy, thereby provides us an answer to the problem of cleaner and greener energy. This report presents different components and its various configurations along with the feasibility of using solar energy as a potential source of heat for deriving a Stirling engine. There is design and calculations of different components of Solar Stirling engine. Stirling engines exhibit the same processes as any heat engine: compression, heating, expansion, and cooling. Stirling engines operate on a closed regenerative thermodynamic cycle. Gas is used as the working fluid, and undergoes cyclic compression and expansion in separate chambers with changing volume. In a typical Stirling engine, a fixed amount of gas is sealed within the engine, and a temperature difference is applied between two piston cylinders. As heat is applied to the gas in one cylinder, the gas expands and pressure builds. This forces the piston downwards, performing work. The two pistons are linked so as the hot piston moves down, the cold piston moves up by an equal distance. This forces the cooler gas to exchange with the hot gas. The flow passes through the regenerator, where heat is absorbed. Fig. 1 shows the stirling cycle operation.

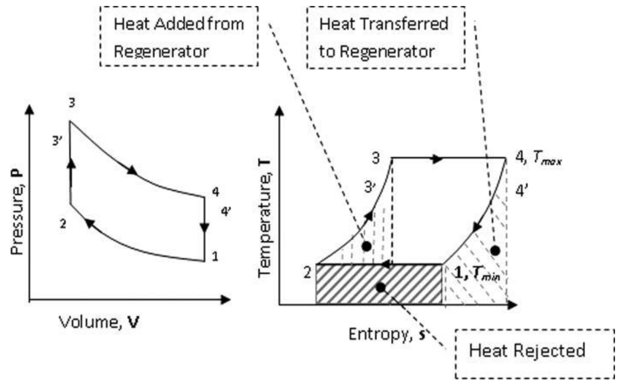

Fig. 1 Stirling cycle

Rakesh K. and Bumataria [1] made an attempt to study stirling engine, its applications and its suitability to use solar energy as pumping water in rural sector. Review of study is done for the development of solar stirling engine which will help in development of the engine which can be used for pumping water at rural areas using solar energy as a source. The engine developed will have its wide application not only in rural sector but also for generating electricity by attaching a generator of required capacity to the shaft of an engine. Alokkumar et al. [2] worked to design the Solar Stirling engine. The following report presents the design selection process of solar stirling engine. A Stirling engine is the approximate the theoretical Carnot cycle engine and consists of rapid heating and cooling of a gas within piston/cylinder device. There is no exhaust or intake, therefore the stirling engine consider as an external combustion engine, means the heat applied externally. We intended to utilize power of the sun to provide necessary energy to the system instead of burning conventional fuels. The main purpose of the project is to promote the use of Stirling energy in 'green energy' applications. Tlili et al. [3] ,studied heat transfer phenomenon in different parts of stirling engine such as heater, cooler analysis, engine configuration and classification, working fluid, power and speed control, performance governing factor and different characteristics of stirling engine. Asnaghi [4] ad done numerical simulation and thermo dynamic analysis of solar stirling engine. Some imperfect working conditions, piston's dead volumes and work losses are considered in the simulation process. Considering an imperfect regeneration, an isothermal model is developed to calculate heat transfer. Heater and cooler temperatures, working gas, phase difference, average engine pressure, and dead volumes are considered as effective parameters. By variation in effective parameters, stirling engine performance is estimated. Brooks et al. [5], investigates the optimization of the performance of a solar powered stirling engine based on finite-time thermodynamics. Heat transfers in the heat exchangers between a concentrating solar collector and the stirling engine is studied. The irreversibility of a stirling engine is considered with the heat transfer following Newton's law. The present work explained the design and fabrication of the stirling engine. The design calculation are done with as per standards and the experimental prototype striling engine power out is identified.

II. DESIGN OF STIRLING ENGINE

A. Assembly model of stirling engine

Computer aided design is the integral of computer systems to assist in the creation, modification of a drawing. It is the technology concerned with the use of digital computers to perform certain functions in drawing design and production. CATIA is one of the most comprehensively wide used engineering tools in the industry used by thousands of companies around the world. CATIA consistent of design and styling domains. It performs the tools needed to execute 3D part and assembly drawing design, extensive generation of production drawing and create in context, wire frame construction elements and advanced surfaces. A clay modeling style tool is also provided to assist with the initial innovative thoughts.

Workbenches of another CATIA domain include prod synthesis, equipment and system engineering analysis machining and infrastructure. These provide integrated interference checking, real time rendering capabilities and data exchanges using common industry standards such as IGES format and stereolithographic. CATIA enables the creation of 3D parts, from 3D sketches, sheet metal, composites, molded forged or tooling parts up to the definition of mechanical assemblies. The software provides advanced technologies for mechanical surfacing & BIW. It provides tools to complete product definition, including functional tolerances as well as kinematics definition. CATIA provides a wide range of applications for tooling design, for both generic tooling and mold & die. Fig. 2 shows the assembly model of the stirling engine.

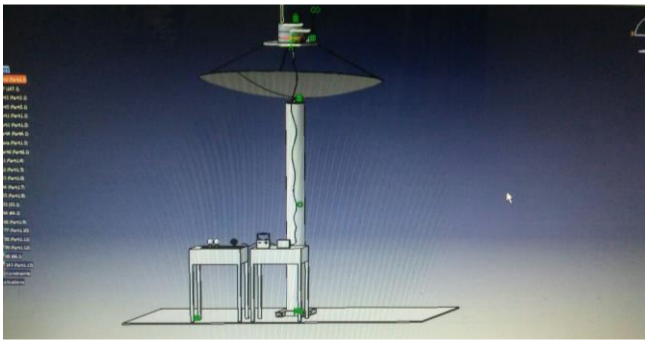

Fig. 2 CATIA Model

The flowchart of the stirling machine operation is shown in Fig. 3.

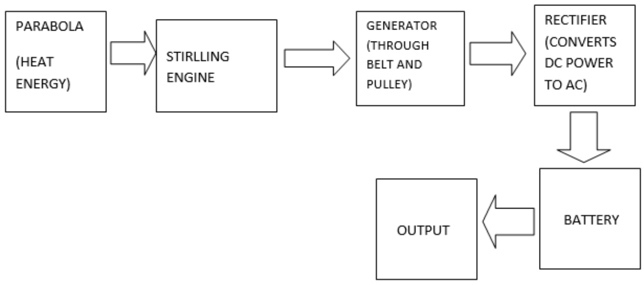

Fig. 3 Flowchart of operation

B. Design calculations

The design calculations are shown below for different components used in the stirling engine.

Round Parabola
f = (D ×D) / (16 ×c)
f = (395× 395) / (16 × 45) =216.70mm~220mm
Length of minor axis=260mm
Length of major axis=395mm
Area of disc=π×a×b=π×260×395=322641.56 mm2=32.26 cm2

Hot Cylinder
Assuming a pressure of 2 bar =0.2MN/m2
External diameter of hot cylinder (Do)= 120mm
Thickness of cylinder (thc) = P×D/2σt =0.2×120/2×48
thc= 0.25 mm≈1.5mm
Internal diameter of hot cylinder (Di)= 120-2×1.5=117mm
Length of hot cylinder (Lh) =90mm

Dispenser
Diameter of hot piston (Dp)= 95mm (1mm clearance on each side)
Thickness of hot piston (Thp)=0.03×Dp= 1.35mm≈0.25mm
Length of hot piston (Lp)= 20mm

Flywheel
Shaft diameter (Ds) =4mm
Diameter of the fly wheel (Df = 40mm
Thickness of the rim (tf) = 3mm
Hub diameter (dh)= 2×Ds= 8mm
Length of the hub (lh) = 2×Ds= 8mm
Taking a speed of 600 RPM
We have speed (n) = 600/60 = 10rev/s
Change in energy E= CE×P/n = 0.29×5/10= 0.145J

Crank Shaft
Diameter of Crankshaft (d1) = 4mm
Length of crankshaft part1 (l1) = 45mm
Now radius of gyration of the shaft (k) = d/4= 4/4 =1mm
Also we have constant K= 4/25000
(fcr1)= fc/[1+K×(l/k)] = 213/[1+4/25000×(45/1)]
=211.47MN/m2<268MN/m2 which is yield strength of mild steel
Hence the design is safe
Similarly for crankshaft parts 2, 3, 4 the lengths are as follows

Length of crankshaft part2 (l2)=30mm
Length of crankshaft part3 (l3)= 20mm
Length of crankshaft part4 (l4)= 30mm
Crippling stress values for part 2, 3, 4 are as follows
fcr2=213/[1+4/25000×(30/1)] = 214.02MN/m2<268MN/m2
fcr3=213/[1+4/25000×(20/1)]=212.32MN/m2<268MN/m2
fcr4=213/[1+4/25000×(30/1)]=214.02MN/m2<268MN/m2

Cold cylinder
Assuming a pressure of 2 bar = 0.2MN/m2
External diameter of cold cylinder (do)= 20mm
Thickness of cold cylinder (tcc)=P×do/2×σt =0.2×20/2×68
tcc=0.029mm=1.5mm (due to standard size of tube)
Internal diameter of cold cylinder (di)=20-3=17mm
Length of cold cylinder (lc)= 40mm

Cold Piston
Diameter of cold piston (dp)= 19mm
Thickness of cold piston (tcp)= 0.03×dcp=0.57mm
≈ 1mm (due to standard thickness of tube)
Length of cold piston (lp)= 25mm

For direct Radiation
Latitude (let)= 30°
Hour angle= 0°
Reflectivity of the material =0.96
Tilt angle Σ =90°
Declination , d = 23.5°
Altitude angle β at solar noon βmax = 90-(l-d) =90- (30-23.5)= 83.5°
At solar noon solar azimuth angle γ =180°
Wall azimuth angle α = 180 – (γ-ξ) = 0°
Incident angle θ overall = Cos-1(Cosβ×Cosα) =Cos-1(Cos89.53×Cos180)= 90.47°
Direct radiation IDN =A×e(-B/Sinβ) =1080×e(-.21/Sin83.5) = 874W/m2
IDN* Cosθ =874×Cos90.47 =-7.16W/m2
Diffuse radiation, Id
View factor Fws= (1+CosΣ)/2
Diffuse radiation, Id =C×IDN×Fws =0.135×874×0.5= 58.99W/m2
Reflected radiation for 0.96(ρg)
Ir=(IDN+Id)×ρg×Fwg=(874+59.99)×0.96×0.5 =448.31W/m2

III. RESULTS AND DISCUSSION

A. Experimental calculations

The power, output is calculated by taking the readings of speed using tachometer for every hour. The readings are taken for two days and thereby comparing the results. The power output of the stirling engine for one set of observation is calculated with the use of the below relations.
The power output, at time 9 am to 10 am, the obtained RPM at the crankshaft is 151RPM.

P = (2πNT)/60000
T=weight of the flywheel×radius of flywheel
T =20×6 =0.12 N-mm
P= (2×3.14×151×0.12)/60000
P=1.916Watts

Tables I and II show the Day-1 and Day-2 observations.

TABLE I. DAY-1 OBSERVATIONS

Sl. No	Duration (Hours)	Speed (RPM)	Power output (Watts)
1	9-10	151	1.916
2	10-11	164	2.081
3	11-12	183	2.322
4	12-1	200	2.54
5	1-2	193	2.449
6	2-3	182	2.309
7	3-4	169	2.093

TABLE II. DAY-2 OBSERVATIONS

Sl. No	Duration (Hours)	Speed (RPM)	Power output (Watts)
1	9-10	148	2.878
2	10-11	156	1.979
3	11-12	180	2.284
4	12-1	198	2.512
5	1-2	187	2.373
6	2-3	171	2.179
7	3-4	163	2.068

On comparing the hour to hour calculations on two days, the maximum power output is obtained at noon time between 12'o clock to 2'o clock.

IV. CONCLUSIONS AND FUTURE SCOPE

We conclude that using solar stirling engine with round parabolic collector we can multi the power rather using other engines as air medium. Using air as a medium, we can reduce thermal losses. By using mechanical tracking, system cost is reduced rather than other using automatic sensor tracking system. In future, with the use of solar sensor tracking mechanism we can enhance the efficiency and increasing the size of cylinder the capacity of the engine can be increased. Similar way with the use of multiple solar stirling engines

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