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# Design and Testing of Solar Powered Stirling Engine

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**Abstract-**This report presentsdifferent components and its various configurations along with the feasibility of using solar energy as a potential source of heat for deriving a stirling engine. In addition to this it contains the design details of various parts of stirling engine and details of materials used.Engine parts being of mild steel, aluminium and cast iron so turning, facing, grinding, cutting, threading, tapping operations were used in the fabrication of stirling engine. There is design calculation of different components of stirling engine and parabolic dish as hot cylinder calculations, hot (Displacer) piston calculations, cold cylinder calculations, cold piston calculations, connecting rod calculations, calculations of flywheel, parabolic dish calculations is performed.

**Keyword-**Joint board, hot cylinder, displacer piston, cold cylinder, cold piston, connecting rod, flywheel, slider, crank, rotating disc, connecting pins, shaft, frame, dish, piston holder, sealing nipple.

## 1. Introduction

Energy crisis is a harsh reality in the present scenario. Conventional fossil fuels like coal, natural gas, petroleum products etc. get exhausted in the near future and also the prices of these fuels are increasing day-by-day. Pollutionand global warming are drawback with the use of conventional fossil fuels. So, use of alternative sources which provide clean and green energy is important.This report demonstrates that stirling engine which is an external heat engine can be used as an efficient and clean way of producing energy with help of concentrating a parabolic reflector.. It is used in some very specialized applications, like in submarines or auxiliary power generators. A stirling engine was first invented by Robert Stirlinga Scottish in 1816.

A Stirling engine is a heat engine operating by cyclic compression and expansion of the working fluid (air or other gas) at different temperature levels such that there is a net conversion of heat energy to mechanical work.When the gas is heated, because it is in a sealed chamber, the pressure rises and this then acts on the power piston to produce a power stroke. Whenconfine gas is cooled, the pressure drops and then piston to recompress the gas on the return stroke, giving a net gain in power available on the shaft. The working gas flows cyclically between the hot and cold heat exchangers. The Stirling engine contains a fixed amount of gas that is transferred back and forth between a cold end and a hot end. The displacer piston moves the gas between the two ends and the power piston is driven due to the change in the internal volume as the gas expands and contracts. This report presents an external combustion engine. The engine is designed so that the working gas (air) is generally compressed in the colder portion of the engine and expanded in the hotter portion resulting in a net conversion of heat into work. So, aStirling engine system has at least one heat source, one heat sink and heat exchangers and transmitted from a heat source to the working fluid by heat exchangers and finally to a heat sink.
There are three types of Stirling engines that are distinguished by the way they move the air between the hot and cold sides of the cylinder is **alpha, beta and gamma** types, In a beta configuration similar to the engine used in this study, A beta Stirling has a single power piston arranged within the same cylinder on the same shaft as a displacer piston The displacer piston shuttle the working gas from the hot heat exchanger to the cold heat exchanger. The displacer is a special-purpose piston; used in Beta and Gamma type Stirling engines, to move the working gas back and forth between the hot and cold heat exchangers. The working gas is pushed to the hot end of the cylinder so; it expands and pushes the power piston. The displacer is large enough to insulate the hot and cold sides of the cylinder thermally and to displace a large quantity of gas.

## 2. Calculations

**2.1 Hot cylinder calculations**:

Assuming a pressure of 2 bar = .2MN/$m^2$

External diameter of hot cylinder ($D_o$)= 50mm

Thickness of cylinder($T_{hc}$)= P*D/2$\sigma_t$ =.2*50/2*48

$T_{hc}$ = .104 mm≈1.5mm (due to standard size of tube)

Internal diameter of hot cylinder ($D_i$)= 50-2*1.5=47mm

Length of hot cylinder ($L_h$)= 3* $D_i$=141mm≈140mm

**2.2 Hot(Displacer) piston calculations**:

Diameter of hot piston ($D_p$)= 47-2=45mm (1mm clearance on each side)

Thickness of hot piston ($T_{hp}$)=.03*$D_p$= 1.35mm≈.25mm (due to standard size of aerosol bottle)

Length of hot piston ($L_p$)= 80mm

**2.3 Cold cylinder calculations**:

Assuming a pressure of 2 bar = .2MN/$m^2$

External diameter of cold cylinder ($d_o$)= 32mm

Thickness of cold cylinder ($t_{cc}$)=P*$d_o$/2*$\sigma_t$ = .2*32/2*68

$t_{cc}$=.047mm=1.5mm (due to standard size of tube)

Internal diameter of cold cylinder ($d_i$)= 32-3= 29mm

Length of cold cylinder ($l_c$)= 67mm

**2.4 Cold piston calculations**:

Diameter of cold piston ($d_p$)= 29mm

Thickness of cold piston ($t_{cp}$)= .03*$d_{cp}$= .87mm≈ 1mm (due to standard thickness of tube)

Length of cold piston ($l_p$)= 35mm

**2.5 Connecting rod calculations**:

Diameter of connecting rod($d_1$)= 6mm

Length of connecting rod part1($l_1$)= 11.5mm

Now radius of gyration of the rod (k)= d/4= 6/4 = 1.5mm

Also we have constant K= 4/25000

Crippling stress on the rod ($f_{cr1}$)= $f_c$/[1+K*(l/k)] = 213/[1+4/25000*(11.5/1.5)]

=212.7MN/$m^2$<268MN/$m^2$ which is yield strength of mild steel

Hence the design is safe

Similarly for connecting rod parts 2, 3, 4 the lengths are as follows

Length of connecting rod part2($l_2$)=8.5mm

Length of connecting rod part3($l_3$)= 5.5mm

Length of connecting rod part4 ($l_4$)= 4.8mm

Crippling stress values for part 2, 3, 4 are as follows

$f_{cr2}$=213/[1+4/25000*(8.5/1.5)]

= 212.8MN/m$^2$

$f_{cr3}$=213/[1+4/25000*(5.5/1.5)]

=212.8MN/m$^2$

$f_{cr3}$=213/[1+4/25000*(4.8/1.5)]

=212.8MN/m$^2$

**2.6 Calculations of flywheel**:

Shaft diameter ($D_s$)=15mm

Diameter of the flywheel($D_f$)= 118mm

Width of the rim (B) = 25mm

Thickness of the rim ($t_f$) = 5mm

Hub diameter ($d_h$)= 2*$D_s$= 30mm

Length of the hub ($l_h$)= 2*$D_s$= 30mm

Taking a speed of 600 RPM

We have speed (n)= 600/60 = 10rev/s

Change in energy E= $C_E$*P/n = .29*5/10

= .145J

Weight of the flywheel = .75Kg

Velocity of the wheel = π*$D_f$*n = π*118*10

= 3707.1mm/s= 3.71m/s

Mass density of cast iron (ρ) =7200Kg/m$^3$

Centrifugal force on one half of the rim = 2*B*$t_f$*ρ*v$^2$/10$^6$

= 2*25*5*7200*3.71$^2$/10$^6$ = 24.78N

Tensile stress at rim section due to centrifugal force = ρ*v$^2$/10$^6$

=7200*3.71$^2$/10$^6$ = 99.1KN/m$^2$

**2.7 Parabolic dish calculations:**

f = ( D * D ) / ( 16 * c )

where

f= Focal length

c=Depth of dish

D=Diameter

For D=420mm & c=37mm

f = ( 420 * 420) / ( 16 * 37 )=297.97mm~**298mm**

Length of minor axis=420mm

Length of major axis=525mm

Area of disc=π*a*b=π*525*420=692721.2 $mm^2$=69.3 $cm^2$

**2.8 Calculation for direct radiation:**

Latitude (let)= 30˚

Hour angle= 0˚

Reflectivity of the material = .96

Tilt angle Σ =90˚

Declenation , d = 23.5˚

Altitude angle β at solar noon $\beta_{max}$ = 90-(l-d) =90- (30-23.5)

= 83.5˚

At solar noon solar azimuth angleγ =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 $I_{DN}$ =A*exp(-B/Sinβ) =1080*exp(-.21/Sin83.5)

= 874W/$m^2$

$I_{DN}$* Cosθ =874*Cos90.47 =-7.16W/$m^2$

Diffuse radiation, $I_d$

View factor $F_{ws}$= (1+CosΣ)/2

Diffuse radiation, $I_d$ =C*$I_{DN}$*$F_{ws}$ =0.135*874*0.5

= 58.99W/$m^2$

Reflected radiation for .96 ($\rho_g$) $I_r$=($I_{DN}$+$I_d$)*$\rho_g$*$F_{wg}$

= (874+59.99)*.96*0.5

=448.31W/$m^2$

## 3. Fabrication Details

The fabrication details of different parts of the engine are given below with the detail of the operations performed

**Fig.1 TheStirling Engine**

**3.1 Joint Board -**Joint board is a cast iron rectangular slab of two overlapping holes were made on both sides of the slab. The holes were overlapped in order to provide transition for working fluid from hot cylinder to cold cylinder. Hole for hot cylinder was 50mm diameter and 32mm for hot cylinder. Tapping of M16 was performed on both holes to provide internal threads so as to fit cylinders in them. Tapping of M16 gave us 2mm pitch for threads.

**3.2 Hot Cylinder -** Hot cylinder is 140mm long cylinder with 50mm external diameter. Cylinder thickness for hot cylinder is 2mm. External threads were provided on it to so as to fit it on respective hole with M16. Threads were provided upto 50mm from front side. On the posterior side a circular aluminium plate was welded to the cylinder where heat absorption will take place.

**3.3 Cold Cylinder -** Cold cylinder is 67mm long mild steel cylinder with 32mm external diameter. Threading was provided to one side of it which was to be fit into the joint board hole. Other side was for piston which was connected to crank with a connecting pin.

**3.4Hot Piston -** An aluminium pesticides bottle was used as piston for hot cylinder. Connecting rod was placed in it with help of teflon which was placed in it with internal threading. It was grinded to provide for smooth surface finish so as to provide easy movement inside a hot cylinder.

**3.5 Connecting Rod -** Mild steel rod was used connecting rod for both of the pistons. For hot cylinder the connecting rod was fitted to the hot cylinder with help of threads, with internal threads for teflon block and external threads for connecting rod. For cold piston connecting rod was fitted to the piston with help of a movable pin of 1mm.

**3.6 Final Assembly -** All the components were then assembled on a board with a proper alignment with help of welding. Then the final assembly was placed onto a frame so that it can be properly focused on with help of parabolic dish.

**3.7 Parabolic Dish -** A parabolic dish of 420mm minor axis and 525mm major axis with 37mm depth. Focal point of the dish is 298mm. The dish was first mended for minor flaws with hammering. Then the dish was first cleaned with emery paper and a layer of reflective paper was placed on it for reflectivity. A convex lens was further procured to get a better focus of the incident light on the hot cylinder.The focal length of the lens is 6 inchs.

## 4. Conclusion

It is concluded that the simple design analysis of stirling engine operated in two heat source with help of solar energy. The shaft rotates when solar energy imparted on hot zone of the stirling engine. This design of has low hot-side temperatures archive as compared to operated at traditional Stirlingengine so overerallefficiency is low. Friction between different mating parts and proper lubrication are also more important to increase the overall efficiency.

**REFERENCES:**

[1] Snyman H., Harms T.M. and Strauss J.M., (2008) examination of Design analysis methods for Stirling engines. Journal of energy in South Africa, Vol.-19 No.-3, page 4-19.South Africa

[2] Khan K.Y., Ivan N.A.S., Ahmed A.S., Siddique A.H. and Debnath D. (2011) examination of solar dish stirling system and its economic prospect in Bangladesh.International journal of electrical & computer sciences IJECS-IJENS Vol: 11 No: 04, page 7-13.Bangladesh

[3] Mancini T.R. examination of solar-electric dish stirling system development. USA

[4] Kyei-Manu F. andObodoako A. (2005) examination of solarstirling-engine water pump proposal draft. Page 1-15.

[5] Heand M. and Sanders S. examination of design of a 2.5kW low temperature stirling engine for distributed solar thermal generation. American institute of aeronautics and astronautics, page 1-8, USA

[6] Sukhatme S.P. (2007) Principles of thermal collection and storage. McGraw Hill, New Delhi

[7] Duffie,J.A and Beckman (2006) Solar engineering of thermal processes. John willy& sons, INC., London

[8] Rai, G.D (2011) solar energy utilisation. Khanna publishers, India

[9] Renewable Energy focus handbook (2009), ELSEVIER page 335

[10] Valentina A. S., Carmelo E. M., Giuseppe M. G., MiliozziAdio and Nicolini Daniele (2010) New Trends in Designing Parabolic trough Solar Concentrators and Heat Storage Concrete Systems in Solar Power Plants. Croatia, Italy

[11] FOLARANMI, Joshua (2009) Design, Construction and Testing of a Parabolic Solar Steam Generator.Journal of Practices and Technologies ISSN 1583-1078. Vol-14, page 115-133, Leonardo

[12] Xiao G. (2007) A closed parabolic trough solar collector. Version 2 Page 1-28

[13] Brooks, M.J., Mills, I and Harms, T.M. (2006) Performance of a parabolic trough solar collector. Journal of Energy in Southern Africa, Vol-17, page 71-80 Southern Africa