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Review on Striling Engine with Solar Concentrator for Power Generation

Prof. Sanjay Mowade¹, Prof. Anil Ingle², Rimanshu Fating³, Abhijit Chatur⁴, Hasin Bagde⁵,

Devendra Rahangdale⁶

Head of Department of Mechanical Engineering, Smt. Radhikatai Pandav College of Engineering, Nagpur, India¹

Assistant Professor, Department of Mechanical Engineering, Smt. Radhikatai Pandav College of Engineering, Nagpur,

India²

Student, Department of Mechanical Engineering, Smt. Radhikatai Pandav College of Engineering, Nagpur, India ^{3, 4,5,6}

ABSTRACT: Stirling engines work using the heat energy as the energy input and are based on the Stirling cycle It is proposed to develop a Stirling engine for a 1.5 kW electrical output. A receiver for absorbing heat from solar concentrator or a flame will also be developed as an integral part of the engine. The heat available is expected to be at around 750 K. The engine will be tested and characterized in the laboratory using gas or electrical heaters. The estimated thermal efficiency of Stirling engine is expected to be around 37 %.

KEYWORDS: Standalone Solar Dish Stirling, Solar Thermal Power, Performance, Energy Conversion Efficiency, SAM, Techno Economic.

I. INTRODUCTION

Stirling engines are again becoming relevant due to shortage and high cost of fossil fuels. Stirling engines run quietly on combustion of any fuel. Stirling engines have high efficiency and are safe over a wide operating conditions range. Stirling engines do not use valves and are generally compact. Further, these engines are suitable for concentrated form of solar energy which is inexhaustible. However, the insolation is varying and periodic in nature. Hence without large capacity high temperature storage, full day operation is not possible. By worldwide scenario, engines up to 30 kW capacity have been made and some of these have been coupled with dish systems. But, testing over very large number of hours is not done with good number of units.

Stirling engines can also operate on gaseous fuel such as biogas generated from bagasse, cow dung, fuel wood, solid bio-waste etc. and LPG, Natural gas, producer gas etc. Use of closed cycle Stirling engines eliminates components like condenser, cooling tower, feed pump, boiler etc. compared to Rankine cycle. Thermal efficiency of engine. based on Stirling cycle is expected to be higher than that of Rankine cycle. This also may prove to be cheaper option compared to solar photovoltaic units for 1.5 kW and higher capacity levels. It will, at least partially, help to overcome the present problem of scarcity of electrical energy in India, especially in remote regions. There are 43,000 villages in India [1] to be electrified which have features as follows. These villages are in difficult terrain in far-flung areas, 3 - 30 km away from grid, have number of households below 200, average population < 500, with power requirement quite low (supply only for 4-6 hr/day) for minimal existing facilities. The grid connection for such villages is a very costly proposition and hence not easily taken up. This system can be a blessing for these villages. Therefore, Stirling engines with capacity of at least 1.5 KW to suit the minimum requirements seem to be the most viable option.

Main aim is to design and develop a Stirling engine for 1.5 KW capacity Literature review is carried out for Stirling engine for various capacities. The Stirling engine is analyzed using second order cyclic analysis approach. This includes the calculation of theoretical power output and heat input under predecided conditions. It also includes calculation of losses in the power output and heat input. Optimization of engine is done with univariate method considering effect of hollow displacer and overlapping volume. At the end we are in position to get the engine efficiency. The engine considered is a single cylinder, beta configuration with rhombic drive operating with Hydrogen as the working fluid with mean pressure of 30 bar, speed 1440 rpm with gas temperature range of 750 k to 350 k. The present status of the work indicates that the estimated thermal efficiency of the engine will be around 38 %. The



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development will provide the electrical output of 1.5 KW at 24 Hz which can be modified to 50 Hz using electronics. This may be used for lighting, fans, charging the storage batteries, for running small capacity pumps for irrigation application etc. in remote areas. It can be effectively used for a group of 3-4 households having enough cattle to supply bio-gas for gas-based systems or hybrid systems.

III. LITERATURE REVIEW

Mahendru make case study on solar powered water pumping project in Samastipur, Bihar, India. In this technology solar panel operating voltage-220V×8 panels, maximum power per panel-230 W, maximum power of solar array1840 W, submersible pump-2HP, water discharge12000 lit/hour on sunny day, size of each pond-1 Acre, total ponds-44. Khandker et. al. suggested that the provision of high quality energy services to rural areas has lagged behind urban areas. It is both financially and physically more difficult to service remote and poor populations compared to those living in urban areas. There are still significant challenges in improving the reliability of power supply in rural area in the country. The challenges are basically two-fold: How to improve the access of rural households to electricity beyond the current rate of 56 percent and how to ensure reliable and adequate supply of electricity. Although rural energy activities receive significant support from the Government of India, our findings would tend to confirm that there is still a long way to go to ensure that the rural poor can take advantage of the many benefits of modern energy and the services that they provide to consumers.

Christoph et. al. analyze the Stirling engine from economic point. They pointed that (i) Only a very small power operation can carry out a Stirling engine, which contributes a lot to energy conservation. (ii) If solar is used to produce energy for the Stirling engine, the cost would be cut down for quite a lot, it costs much to manufacturing. (iii) Stirling engine exhausts cleanly and avoid lot of pollution, which reduce so much cost for pollution control and government. (iv) At the end of 18th century and the early 19th century the heat engine efficiency is very low, only 3% to 5% but now the efficiency of Stirling engine can come up to 80% or even more. So another part of cost is saved.

Risberg built a Stirling engine with specification as follow: Crankshaft – 7 inches long with a $\frac{1}{2}$ inch depth, Crankshaft supports – 4.5 inches high, 1.25 inches wide, Pressure Vessel and displacer – 3 9/16 inch diameter, Displacer Bottom – 1.3 inches high, Displacer Top pin – 2.2 inches high, Stand – 3.5 inches high. Efficiency, Torque, Power, Angular speed, and acceleration are all unknown since the engine did not successfully run. Kwankaomeng and Burapattanon [12], develop a gamma type Stirling engine with double power piston working temperature range of 512-54°C at the hot head engine and air cooler section respectively. The prototype has displacer diameter and stroke of 218.5 mm and 80 mm respectively. And power piston diameter and stroke of 98.5 mm and 110 mm respectively. The engine was improved and tested over wide range of operating conditions for comparison. The results indicate that power of the improved prototype is better than unpressurized engine and using air as working gas. The maximum engine power was 5.05 W at 68.7 rpm and maximum torque was 0.978 N-m at 45 rpm. Maximum engine speed was 130 rpm at temperature of 560° C. The test results showed that the engine started operation in 5 minute at temperature about 490° C on the hot engine head and temperature of 47° C at air cooler section.

Hirata et. al. evaluate performance for a 100 W Stirling engine on the basis of pressure, pressure loss, leakage of working gas, buffer space loss, indicated work and power, mechanical loss etc. analytical and compare with model. From this they conclude that 1. The pressure loss at the regenerator, the gas leakage and the heat transfer in the buffer space was presented. It can simulate the engine performance adequately. 2. The buffer space loss of the prototype engine is estimated adequately, when it is considered the heat transfer with the number of heat transfer unit, NTU=0.1.3. Working gas flowed without an enough extending in the regenerator in the prototype engine.

Koichi develop compact and low cost a gamma type Stirling with simple moving-tu4be-type heat exchangers and a rhombic mechani4sm. Its target shaft power is 50 W at speed of 4000 rpm and mean pressure of 0.8 Mpa. The test was done in without load, using air in atmospheric condition. Also, a mechanical loss measurement was done in highly pressurized condition in which the engine was driven by motor.

Thombare and Verma published review paper on isothermal analysis, heat transfer in isothermal and adiabatic model, maximum obtainable efficiency, Schmidt's theory, heat transfer phenomenon in different parts of sterling engine such as heater, cooler, regenerator analysis, engine configuration and classification, working fluid, power and speed control, performance governing factor and different characteristics of Stirling engine. Stirling Energy Systems (SES). Company in partnership with Sandia National Lab managed to break the world record for solar-to-grid conversion efficiency at an amazing 31.25 % on January 31, 2008. SES Serial 3 was erected in May 2005 as part of the Solar Thermal Test Facility



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which produced up to150kW of grid ready electrical power during the hours of sunlight. Each dish consisted of 82 mirrors that can focus the light into an intense beam (Systems, 2008). SES solar Stirling engine, named Sun Catcher, was awarded the 2008 Breakthrough Award winner by Popular Mechanics for its role as one of the top 10 world-changing innovations. The Sun Catcher is a 25 kWe solar dish Stirling system which uses a solar concentrator structure which supports an array of curved glass mirror which are designed to follow the sun and collect the focused solar energy onto a power conversion unit. The diagram below illustrates the workings of SES's Sun Catcher.

Minassians and Sanders make feasibility study of a low-cost solar-thermal electricity generation technology, suitable for distributed deployment, based on nominating solar concentrators, integrated with free-piston Stirling engine devices incorporating integrated electric generation. Concentrator collector operates at moderate temperatures, in the range of 120°C to 150°C. This temperature range is consistent with the use of optical concentrators with low-concentration ratios, wide angles of radiation acceptance which are compatible with no diurnal tracking and no or only a few seasonal adjustments. Therefore, costs and reliability hazards associated with tracking hardware systems are avoided. They further outline the design, fabrication, and test results of a single-phase freepiston Stirling engine prototype. A very low loss resonant displacer piston is designed for the system using a very linear magnetic spring. The power piston, which is not mechanically linked to the displacer piston, forms a mass-spring resonating subsystem with the gas spring, and has a resonant frequency matched to that of the displacer. The design of heat exchangers is discussed, with an emphasis on their low fluid friction loss; an appropriately dimensioned Stirling engine candidate is discussed.

Wood et. al. preliminary design a linear motion free-piston Stirling engine / blower coupled to a rotary turbine / generator. The design combines several features of prototype free-piston machines that are nearing commercial production. The Stirling driver is comprised of two conventional, displacer types, free-piston engines configured as a dynamically balanced opposed pair. Using the outer face of its power piston, each engine drives a single acting blower. The single turbine / generator use commercial units and are separate from the engines and connected by ductwork. The engines and turbines utilize the same helium working fluid.

Moon and Miller complete a rigorous computational model of the engine using Fluent fluid dynamics software. After that attempt they made to model the engine in Solidworks Flueworks application, that software proved inadequate for analyzing the transient states present in Stirling engine operation. Then they conduct another experiment in order to determine the actual heat flux concentrator capable of producing, in order to closely match the performance of engine with that of our dish. Finally, they finalize all design elements and. They also wrote all CNC code using Solidworks and Mastercam, in order to do the required machining using SDSU's facilities.

Kangtrageal and Wongwises published a review of solar power Stirling engine. They give some idea about low temperature differential Stirling engine, its characteristics. Also state that engine operation of the Stirling engine depends on the material used for construction. Engine efficiency ranges from about 30% to 40% resulting from a typical temperature range of 923-1073 K and a normal operating speed from 2000 to 4000 RPM, motion diagram, engine indicated work, Stirling engine feasibilities for rural and remote areas, engine optimization techniques, utilization of solar energy using concentrating collector, solar disc technology.

IV. OBJECTIVES

1) To fabricate the prototype Stirling Engine as a proof of concept.

2) To design a Stirling Engine that is capable of running on any source of external heat supply

3) To test the engine's performance and compare it with the theoretical calculate.

V. ADVANTAGESTRILING ENGINE

1. A continuous combustion process can be used to supply heat, so most types of emissions can be reduced.

2. In some cases, low operating pressure allows the use of lightweight cylinders.

3. They can be built to run quietly and without an air supply, for air-independent propulsion use in submarines.

4. They are extremely flexible. They can be used as CHP (combined heat and power) in the winter and as coolers in summers.

VI. DISADVANTAGESTRILING ENGINE

1. Stirling engine designs require heat exchangers for heat input and for heat output, and these must contain the pressure of the working fluid, where the pressure is proportional to the engine power output.



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2. Dissipation of waste heat is especially complicated because the coolant temperature is kept as low as possible to maximize thermal efficiency.

3. Stirling engines, especially those that run on small temperature differentials, are quite large for the amount of power that they produce.

4. A Stirling engine cannot start instantly; it literally needs to "warm up".

5. Power output of a Stirling tends to be constant and to adjust it can sometimes require careful design and additional mechanisms.

VII. SCOPE OF WORK

1) The hybrid Stirling engine we designed and fabricated was in two pieces: a normal Stirling engine that could be heated externally using an open flame and a detachable solar concentrator that could be placed in front of the Stirling engine to take advantage of solar heat.

2) A gamma configuration of the engine was chosen, whose working shall be explained further in this report.

3) The solar concentrating unit consisted of a solar reflector, similar to the ones being used in solar cookers in the most rural areas. Its design was simple and with the right focal length in the curved mirror, the heating of the displacer head would be most efficient.

4) The aim of choosing this design was to make the manufacturing cost of this engine low and keep it simple. The design and fabrication of the engine are also documented in this report.

VIII. CONCLUSION

Finally, throughout the process of designing manufacturing and testing our Stirling engine, we have uncovered many new insight problems and solutions concerning the different portion of the engine. We applied our knowledge of thermodynamics to the design of optimization. The optimized is simulation and a comparison with the initial design is carried out.

A study of the performance of the Dish/Stirling system for generating electricity was made, using a mathematical model coupling each of its subsystems. The temperatures reached at the inlet of the Stirling engine by the two working fluids used (hydrogen and helium) were estimated and compared. We can conclude that hydrogen is the good working fluid in the transport of energy at high temperature to drive the Stirling engine. It is then used in the rest of the work to estimate the electrical power produced by the system. Based on calculations, the performance of the subsystems was estimated from the mathematical model used. The results were compared with those obtained experimentally existing in the literature.

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