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Design Fabrication and Performance Analysis of Stirling Engine

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ABSTRACT

Under the assumption that the rate of population growth is constant and the consumption rate of energy is same as to date, then the energy reservoir will vanish within 320 years. We have to think about an engine, which is working under fixed quantity of working medium (air or inert gas) and heat energy from the any resource (solar, coal, bio fuel etc., but not petrol or diesel). This is what we are going to achieve by this work by fabricating a stirling engine, which is actually an external combustion engine working under a fixed quantity of air as a working medium. Studies were already conducted on this type of engine by changing various heating (solar, bio fuel etc.,) and cooling methods, but, to the best of our knowledge nobody were conducted its performance by varying the displacer length. Our project involves the design and fabrication of a stirling engine model and its detailed performance analysis with respect to the length of displacer. Displacer is an important part in the stirling engine with direct the working medium from the hot end to cold end or vice versa. Changing the dimension of the displacer will change the volume available in the working cylinder and hence changes the available quantity of the working medium. Accurate study is essential to have an idea about the performance under this varying condition of the displacer. In this work, we constructed a model of the stirling engine from a design in which had a provision to adjust the displacer length. After conducting the test, it found that, the displacer dimension severely effecting the performance. The optimum length found to be in between 35 mm and 40 mm for the model analyzed.

Keywords: Stirling Engine, Energy, Design, Performance Analysis.

I. INTRODUCTION

The stirling cycle is the thermodynamic cycle on which the stirling engines work. It was invented by Scottish Church Minister, Robert Stirling with the help of his brother, who was an engineer, in the year 1817. He further developed the engine and got it patented. Stirling cycle was invented before Carnot cycle, which was first, discussed in the book, "Reflections on the Motive Power of Fire," in the year1824 by young French scientist, Sadi Carnot[1]. In Stirling cycle gas like air, helium, hydrogen etc. is used as the working fluid. All the processes of stirling cycle are assumed reversible process, hence when the gas is heated the engine produces work or power and when work is supplied to the cycle it works as the refrigerator or the heat pump. Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas (the working fluid) at different temperatures, such that there is a net conversion of heat energy to mechanical work. The reversed stirling cycle is used extensively in the field of cryogenics as the cryogenerator to produce extremely low temperatures or liquefy gases like helium and hydrogen.

II. METHODS AND MATERIAL

In the fabrication process the designed parts are cross checked and is fabricated accurately, the each part is to be accurate as possible for correct assembly of the parts in the engine.

The fittings used to connect the piston and cranks were made of Steel wool and Mild Steel due to its moderate sliding frictional properties. In fabrication, complication of connecting rod and crank are overcome by our innovative techniques. In addition, the aim is to reduce the cost by the usage of existing product, such as the cylinders where bought from out source with correct design dimensions and it will avoid the practical limitation and risks of manufacturing smooth cylinders, the connecting rods and the crank shafts where also taken from the similar sized Spoke of bicycle and it will avoid the complexity.

The main parts that fabricated for the stirling engine are;

Displacer

The displacer is a main part of the stirling engine and is used for transfer the working medium (air) from the hot end to the cold end or vice versa. In our work we used an adjustable displacer for testing on different displacer size. The displacer is made of steel wool of lite weight and is good in the stirling engine applications since it provides good air compression and expansion inside the working cylinder, the size of the displacer can be fixed for a particular experiment and it can be changed for next experiment by moving the mechanical arrangement provided in the displacer connecting rod. In the working phase when there is a temperature difference between upper displacer space and lower displacer space, the engine pressure is changed by the movement of the displacer. The pressure increases when the displacer is located in the upper part of the cylinder (and most of the air is on the hot lower side). The pressure decreases when the displacer is moved to the lower part of the cylinder. The displacer only moves the air back and forth from the hot side to the cold side. It does not operate the crankshaft and the engine.

Figure 1. The Displacer fabricated from steel wool

Crank shaft

The crank shaft is made up of the spoke of 2 mm dia and is made with two cranks (one is 25 mm crank radius which reciprocate the displacer and other one is 3mm crank radius which is connected to the connecting rod) with mutually perpendicular. The crankshaft is supported by two bearings and one end of it is attached to the flywheel.

Power piston

It is made up of aluminium vessels, connecting pins and synthetic rubber. It is used to convert the air pressure to power motion of the synthetic rubber which delivers the power stroke. The high pressure air is get in to the power piston arrangement through a pneumatic tube and it will make the synthetic rubber sudden expansion and contraction.

Figure 2. The close look of power piston

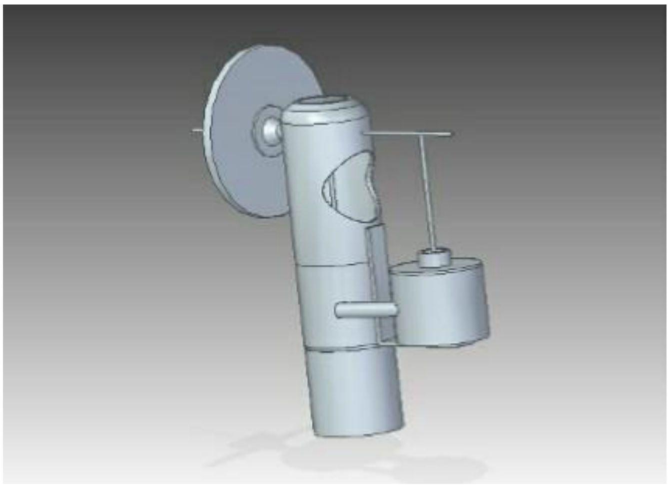

Figure 3. Solid Edge design of stirling engine

Cylinders

The cylinders are those parts which provides the working chamber of the stirling engine and it also provides a rigid support for the whole setup. The cylinders are made of aluminium. It has an excellent surface finish hence it provides the smooth motion of the displacer inside the cylinder.

Flywheel

The flywheel is fabricated from fiber disc and plastic which is connected to the crank shaft. The flywheels are used to gain constant power output from the crank shaft and it has a provision to attach belt for taking power output. Its weight and dimension (110mm diameter and 3 mm thick) was enough to ensure a constant motion of the crankshaft. The output gained through the flywheel and the load test was carried out at the flywheel.

The displacer cylinder and the power piston cylinder are screwed onto the frame. The two cylinders are connected by means of a pneumatic tube which transfers pressurized air. A cooling arrangement is provided and is used to separate the two sides of the displacer cylinder, which act as the hot and cold side. A steel rod is act as a link between flywheel and power piston,

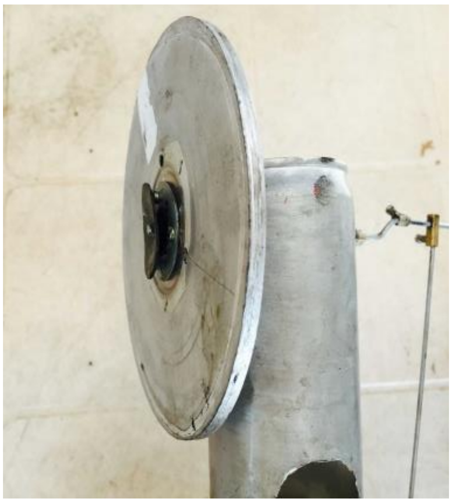

Figure 4. Flywheel of Stirling engine

Figure 5. Stirling engine final assembly

Experimental Setup

Experimental setup is shown in the fig.6. It consists of a linkage assembly for inserting the load. Linkage connection is in a manner that load inserted at the end of the linkage is will be directly transfer to the belt pulley tangentially. Each dead weight used is precisely calibrated before loading.

Predetermined length of the displacer was set on the displacer and the working cylinder was closed carefully. Water was filled in the water container up to the marked lever. Lampovsolve is used as fuel, which was placed under the working cylinder. After a 3minutes warm up time the flywheel was cracked manually. When the engine reached its full speed, it was noted by using noncontact tachometer and tabulated. Then, a small load was placed at the end of the linkage. Reduction in the speed was noted. The load and speed reading were the tabulated. In the next step, the engine was subjected to loading until it stops, during each loading reduction in the speed was noted and tabulated. The load at which the engine stops is the maximum load that the engine can bear at particular displacer length. The above procedure was repeated for different displacer length. In this work load test was done at displacer lengths 25mm, 35mm, 40mm, 45mm.

Figure 6. Stirling engine loading setup

III. RESULTS AND DISCUSSION

Load vs speed characteristic cureve of the stirling engine is shown in the Figure3 and its tabulation is shown in the table.1 to table.4. From the fig.3 it is clearly seen that 360RPM top speed at no load condition was highest obtained to the enigne with displacer length 40mm which is closer to the top speed of the engine with 35mm displacer. The speed of the engine with 40mm displacer is above the speed of the engine with 35mm displacer upto 0.1kg. After crossing 0.1kg loading speed condition is reversed and this is stable upto 0.29kg loading. The engine with 40mm displacer carries more load (up to 0.36kg) before it stops. When the displacer length is increased to 45mm the load carrying capacity of the engine was loas tremetously. The curve shows similar trend as that of 45mm when it is equiped with 25mm displacer. This clearly indicating that the 35mm and 40 mm displacer engine shows better result in the lot. Figure4 shows the speed vs power characteristics of the engine. Refering to that, power also maximum for 35 mm displacer engine (3.6E-2 W). The power of 40 mm displacer engine is closer to it. The maximum power for 35mm and 40mm displacer engine was obtained at a speed of 140RPM. The engine with 45 mm displacer shows less power output and its value is closer to the power output of the 25 mm displacer engine. Refering to the fig.5 speed vs torque characteristics, torque is lenear in trend in the speed range from 100RPM to 235RPM for both 35mm and 40mm displacer engine. For low speed condition the torque is constat for all the four enigne upto 85RPM. Highest torque is obtained for the enigne with 40 mm displacer.

These all are the explainations from the experiment. To explain why 40 mm or 35 mm displacer engine perform well further study is required, expecially numerical analysis from the heat input, heat output, pressure and volume at every instance. But, it is easier to imagine the fact that when an engine is equiped with big size displacer the total available volume of the the working medium will reduce which effects the expansion and contraction of the diaphram mounted over the power cylinder. This is the reason for the lack of performace when the engine is equiped with 45mm displacer size. When the enigne is equiped with very small length displace (like 25 mm), definitly there will be a large amount of working medium avilable for doing work. But the problem is, in every instance the working medium will be in touch with both hot and cold side of the working cylinder. Due to this one end expansion of the working medium will be opposed by the other end contraction.

A stirling engine has large number of working parameters and each on has influence on the performance. In this study all other parameters except displacer length were fixed. The alteration of other parameters like diameter of the working cylinder and power cylinder may or maynot hold the same result which is to be further investigated.

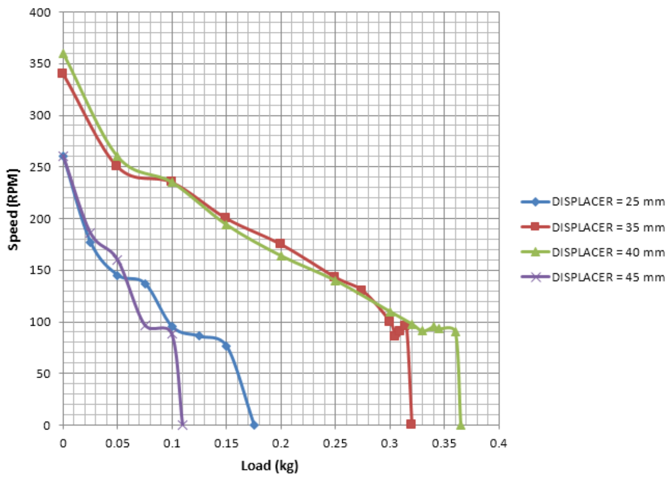

Figure 3. Load vs Speed Characteristics curve of Stirling engine

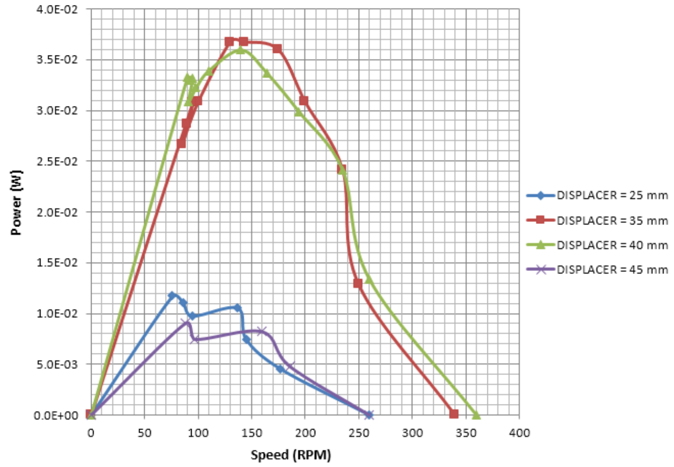

Figure 4. Speed vs Power Characteristics curve of Stirling engine

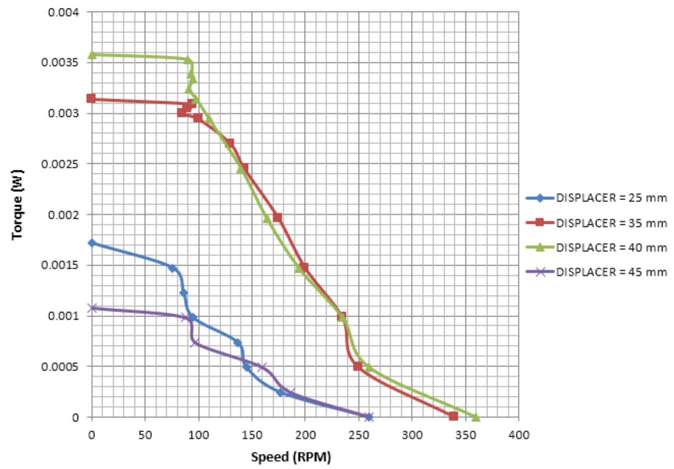

Figure 5. Speed vs Torque Characteristics curve of Stirling engine

Table. 1 Load test on stirling engine with 25 mm displacer length

DISPLACER LENGTH = 25 mm				
load	**Load**	**speed**	**Torque**	**Power**
g	kg	RPM	Nm	W
0	0	260	0	0.0E+00
25	0.025	177	0.000245	4.5E-03
50	0.05	145	0.000491	7.4E-03
75	0.075	137	0.000736	1.1E-02
100	0.1	95	0.000981	9.8E-03
125	0.125	86	0.001226	1.1E-02
150	0.15	76	0.001472	1.2E-02
175	0.175	0	0.001717	0.0E+00

Table. 2 Load test on stirling engine with 35 mm displacer length

DISPLACER LENGTH = 35 mm				
load	**Load**	**speed**	**Torque**	**Power**
g	kg	RPM	Nm	W
0	0	340	0	0.0E+00
50	0.05	250	0.000491	1.3E-02
100	0.1	235	0.000981	2.4E-02
150	0.15	200	0.001472	3.1E-02
200	0.2	175	0.001962	3.6E-02
250	0.25	143	0.002453	3.7E-02
275	0.275	130	0.002698	3.7E-02
300	0.3	100	0.002943	3.1E-02
305	0.305	85	0.002992	0.026633
310	0.31	90	0.003041	0.028662
315	0.315	95	0.00309	0.030742
320	0.32	0	0.003139	0

Table. 3 Load test on stirling engine with 40 mm displacer length

DISPLACER LENGTH = 40 mm				
load	**Load**	**speed**	**Torque**	**Power**
g	kg	RPM	Nm	W
0	0	360	0	0.0E+00
50	0.05	260	0.000491	1.3E-02
100	0.1	235	0.000981	2.4E-02
150	0.15	194	0.001472	3.0E-02
200	0.2	164	0.001962	3.4E-02
250	0.25	140	0.002453	3.6E-02
300	0.3	110	0.002943	3.4E-02
320	0.32	98	0.003139	3.2E-02
330	0.33	91	0.003237	0.03085
340	0.34	95	0.003335	0.033182
345	0.345	93	0.003384	0.032961
360	0.36	90	0.003532	0.033285
365	0.365	0	0.003581	0

Table. 4 Load test on stirling engine with 45 mm displacer length

DISPLACER LENGTH = 45 mm				
load	**Load**	**speed**	**Torque**	**Power**
g	kg	RPM	Nm	W
0	0	260	0	0.0E+00
25	0.025	186	0.000245	4.8E-03
50	0.05	160	0.000491	8.2E-03
75	0.075	97	0.000736	7.5E-03
100	0.1	88	0.000981	9.0E-03
110	0.11	0	0.001079	0.0E+00

IV. CONCLUSION

Gamma type Stirling engine is fabricated as per designed. Performance test on the engine is successfully completed by varying the displacer size. By this experimental anysis on gamma stirling engine. We were concluded that the performance of the stirling engine is greatly influenced on the size of the displacer. The different observations shows that the maximum power was obtained for the engine equipped with 40 mm and 35 mm displacer. This work proves that the swept volume inside the cylinder should be moderate to obtain maximum power output.

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