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MANUFACTURING AND TESTING OF A V-TYPE STIRLING ENGINE

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Abstract: *In this study, a V-type Stirling engine with 163 cc total swept volume was designed and manufactured. Air was used as working fluid. Performance tests were conducted at the range of 1-3 bar charge pressure and within the range of hot source temperature 700-1050 ℃. Experimental results are given. Variation of engine power and torque with hot source temperature at various air charge pressure are tested. Also variation of engine torque with engine speed for different air charge pressure are tested. According to experimental analysis, the maximum engine power was obtained as 21.334 W at 1050 ˚C hot source temperature and 1.5 bars charge pressure.*

Key Words: *Stirling engine; Engine performance; External heating*

I. INTRODUCTION

Energy is one of the fundamental necessities developed and developing countries. Because of increasing depletion of natural energy resources, researchers has focused attention on a new energy sources and on effective means of energy conversion. One of the means of energy conversions is Stirling engine [1,2,]. The Stirling engine was invented in 1816 by Robert Stirling [16]. A Stirling engine is a mechanical device operating on a closed regenerative thermodynamic cycle with repeated compression and expansion of working fluid at different temperature levels [3]. Because heat of high temperature is supplied from external energy sources, Stirling engines can be used for a wide variety of fuels. In addition to use for various fuels, they have advantages of high thermal efficiency, low emissions, selection flexibility on high temperature sources, low noise and vibration [4,5,6]. To increase the specific power of Stirling engines, a number of methods have been used, such as using hydrogen and helium as working fluid at high charge pressure, increasing the tempreture difference between hot and cold sources, increasing the internal heat transfer coefficient and heat transfer surface and using simple mechnical arrangements [14]. Stirling engines are classified into three groups: alpha, beta and gamma. [3].

From the invention to this century, a number of new Stirling engine models have been developed. In the late 1930s, a new interest in the Stirling engine was initiated by the workers of the Philips Company. They developed a Stirling engine at 200 watts power which could run electronic equipment in remote places. Later in 1958, a new research on Stirling engine was carried out by the Philips Company for space power, submarine and vehicular propulsion. In 1967, MAN- MWM Company was involved in development of high power rhombic systems for heavy vehicle propulsion. In 1972, The Ford Motor Company developed the Rinia swash-plate system for automotive engines [7,8]. Kagawa et al [9], developed a miniature Stirling engine producing a maximum output power of 4 W at 0.1 Mpa and 900 rpm. Podesser [10], developed α-type Stirling engine heated by the flue gas of a biomass furnace. At charge pressure of 33 bars, the engine shaft output was obtained 3.2 kW at 600 rpm. Thorsen et al [11], designed, manufactured and tested a beta-type Stirling engine using Natural gas as fuels. The shaft power was obtained as 3 kW at 973 K heater temperature and 9 Mpa charge pressure. Stirling engine-based unit are considered best among the most effective low-power range solar thermal conversion units. In order to analyze and to improve the performance of three main sub-systems of these units, namely the solar receiver, the thermodynamic gas circuit and the drive mechanism, simulation codes are under development worldwide [15].

In the present study, a V-type Stirling engine manufactured and its performance tests were conducted at various charge pressure and heat source temperature.

Test engine

The engine consists of a crankcase, two cylinders and pistons, a crankshaft and two connected rods. The schematic illustration and technical specifications of the engine are shown in Fig. 1 and Table 1, respectively.

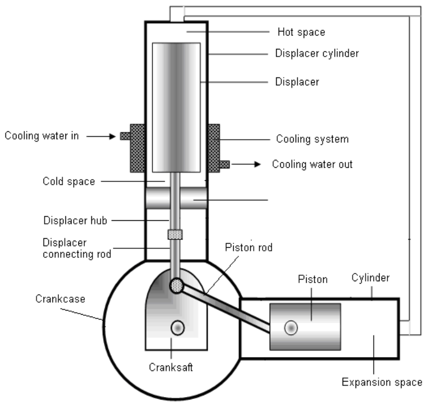

Fig. 1. Schematic illustration of V-type Stirling engine

The crankcase consisted of a body and two side lids. The body and two side lids were made of a piece of circular steel duct and AISI 1080 Special steel, respectively. To prevent leakage of working fluid, the crankshaft totally confined in crankcase. The crankshaft embedded on two side lids of crankcase by means of a leak free bearing. Two cylinders were situated at 90° angles with each other welded on crankcase.

The thermodynamic performance characteristics and design features are predicted preparing a nodal analysis in Fortran.

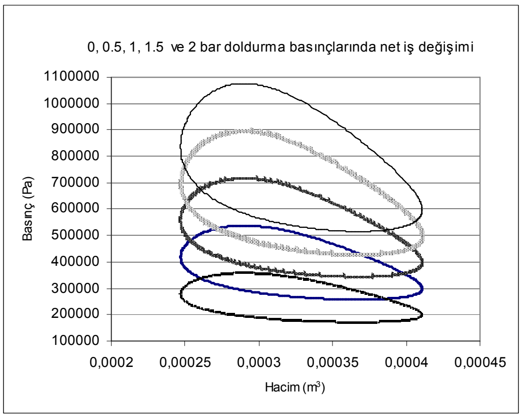

Fig. 2. P-V diagram which is Variation of work at various air charge pressure up to analysis program
Fig.

Table 1. Technical specifications of V-type Stirling engine

Mechanical configuration	Gamma (V)
Swept volume	163 cc
Phase angle	90°
Compression ratio	1.71
Cooling system	Water cooled
Working fluid	Air
Maximum engine power	21.334 W (at 513 rpm)

The crankshaft was made of AISI 4150 steel. Surface of the crank journals is hardened by heat treatment and coated with chromium to prevent from wearing. The surface finish was obtained by grinding in 0.01 mm accuracy. Both ends of the crankshaft were embedded in ball bearings. Two connected rods were embedded on the same crank journal.

The piston was made of high graphite cast iron because of its low friction and expansion with temperature. Between the piston and the cylinder 0.02 mm working clearance was left and no rings were used. The piston was connected to crankshaft by rod made of AISI 1040 steel.

The cylinder consists of a body, cylinder liner and head. The body which made of a piece of circular steel duct was welded on crankcase. Cylinder liner was made of high graphite cast iron because of its low friction, high wear resistance and machining simplicity. The cylinder liner was firmly situated in the body and finished by honing. The cylinder head made of AISI 1040 steel.

Displacer cylinder, which consists of two parts, made of steel with chromium additive to be durability of heat and corrosion. Bottom part of cylinder was welded on crankcase. The inner surface of top part of cylinder was machined super-finish quality by honing. Between the displacer and its cylinder 1 mm working clearance was left to flow from hot space to cold space working fluid. Top and bottom parts were joined to each other with a cast iron bed.

The displacer and displacer rod were made of steel with chromium additive and AISI 2080 steel, respectively. The displacer rod was coated with chromium and its surface machined by grinding. The displacer was connected to the rod made of AISI 1040 steel [13]. The test engine is shown in Fig. 2.

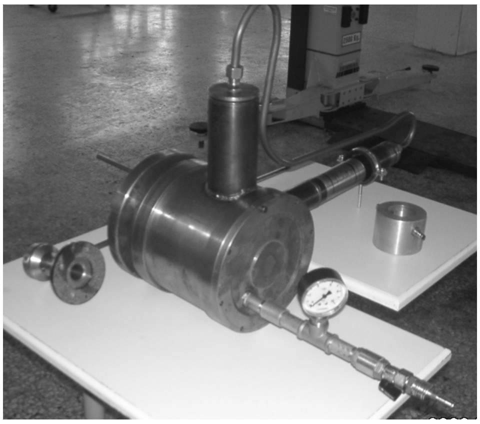

Fig. 4. The test engine

Experimental facilities and test procedure

During the test process, heat was supplied by an electrical furnace, Gallenkof, adjusted to any temperature between 700 ˚C and 1200 ˚C. A thermometer to 0.1 ˚C accuracy was used to measure ambient and furnace temperature. The torque measured by a Prony type dynamometer which was manufactured in the laboratory and has 0.03 Nm of accuracy. To measure the speed of engine a digital tachometer, Shmpo EE-1 trademark, was used. The charge pressure was measured by a manometer having a capacity of 10 bars and 0.1 bar of accuracy. The test equipments are shown in Fig 3.

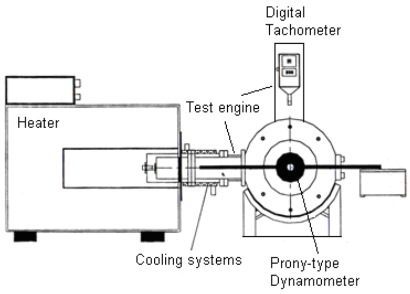

Fig. 3. Schematic illustration of the test equipments

Initially, the test engine was run approximately two hours. After ensuring that no mechanical and thermal problems remained, systematic test was conducted. Air was used as the working fluid. The charge pressure was varied from ambient to 3 bars in increment of 0.5 bars. Systematic tests were initiated at the furnace temperature at 700 ˚C. As the furnace temperature was constant at any desired value, the torque was measured versus the speed of engine. The furnace temperature was adjusted to 700, 800, 875, 950, 1000 and 1050 ˚C. Systematic tests were repeated to different hot source temperature and different charge pressure at the same working conditions.

Test Results and Discussion

Fig. 4 shows the variety of maximum engine power with hot source temperature to different charge pressure. An increase in the hot source temperature, caused to increase in engine speed, torque and power. The increase of engine power with hot source temperature terminates after 1000 ˚C at 3.0 bars charge pressure. This problem results from insufficient heat transfer and leakage of working fluids.

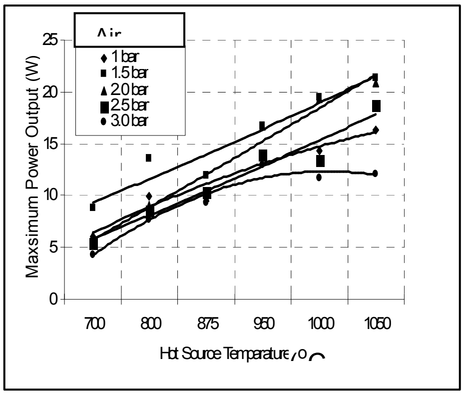

Fig. 4. Variation of engine power with hot source temperature at various air charge pressure.

Fig 5 shows the variation of engine power as a function of charge pressure at various hot source temperatures. Optimum engine power was obtained at the charge pressure of 1.5 bars and hot source temperature of 1050 ˚C. The optimum charge pressure was determined as 1.5 bars. As the charge pressure increases over the optimum charge pressure, the engine power decreases due to leakage problems and insufficient heat transfer. Because of these problems, the engine obtained to stop at the charge pressure of 3.5 bars.

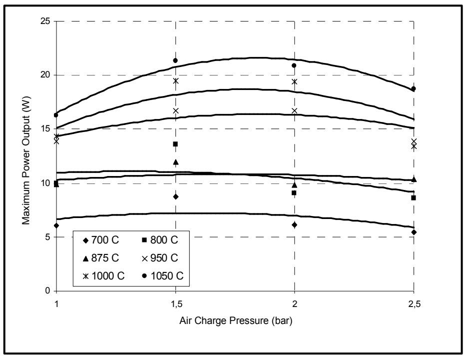

Fig 5. Variation of engine power with charge pressure for different source temperature.

Fig. 6 shows the variation of maximum engine torque with the engine speed at various charge pressures. At 1050 ˚C hot source temperature and the 1.5 bars charge pressure, the maximum engine torque was obtained at 513 rpm as 0.397 Nm. Increase of temperature difference between the hot and cold space causes to increase the engine torque.

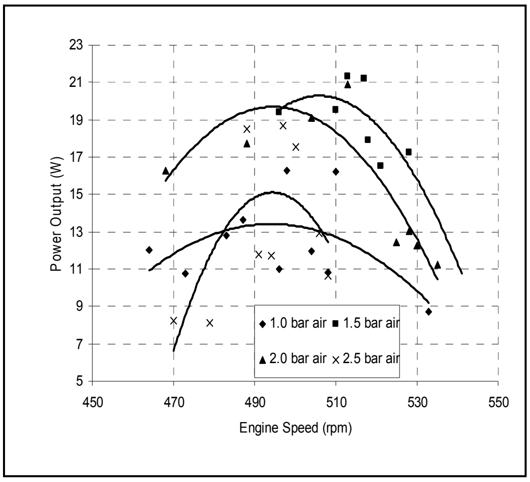

Fig. 6. Variation of engine torque with engine speed for different air charge pressure.

Fig. 7 shows variation of the engine power with engine speed for various charge pressure and 1050 ˚C hot source temperature. After reaching a maximum value at a certain speed the engine power decreased due to inadequate heat transfer. The power is as a function of torque and speed. As the power increase, the speed and torque increase. As seen in Fig. 7, the maximum engine power is obtained at 1.5 bars which is optimum charge pressure.

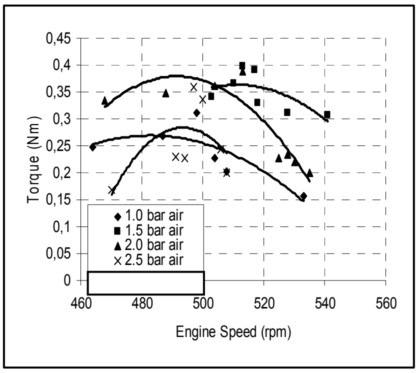

Fig. 7. Variation of engine power with engine speed at 1050 ˚C hot source temperature for different air charge pressure.

Fig. 8 shows variation of the engine power with the hot source temperature at optimum charge pressure. Maximum engine power was obtained as 21.334 W at 513 rpm engine speed and 1050 ˚C hot source temperature. As the hot source temperature increase the engine power also increase. Therefore, the performance of Stirling engine will improve as depend on high temperature resistant material technology.

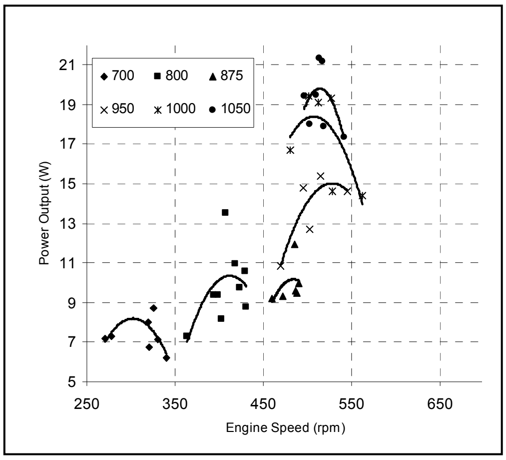

Fig. 8. Variation of engine output with engine speed at various hot source temperature for 1.5 bar charge pressure.

Conclusion

In the present study, a V-type Stirling engine with 163 cc total swept volume was manufactured and performance tests were conducted at various charge pressures and various hot source temperatures. The maximum engine power was obtained as 21.334 W at 513 rpm engine speed and 1050 ˚C hot source temperature. The engine power and torque were increased with the increase of charge pressure and heat source temperature. The engine power was decreased due to leakage problems after a certain charge pressure.

The factors that effect the Stirling motor performance and efficiency are the heat capacity of the working material, friction, mechanical losses and most importantly leakage problems. Efficiency calculations could not be established due to some mechanical and leakage problems. These calculations are planned to be made by working with higher heat capacity fluids like nitrogen, helium and hydrogen as soon as these problems are overcome.

Turkey is an agricultural country with high solar energy potential. An electrical oven was used in the system for the beginning but solar energy with parabolic reflectors is aimed to be used for further studies.

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