MECHANICAL LOSS REDUCTION OF A 100 W CLASS STIRLING ENGINE

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ABSTRACT

We have developed a 100 W class displacer-type Stirling engine named 'Ecoboy-SCM81' since 1995. The original engine has a mechanical seal as an external seal device. On the other hand, a hermetic Stirling engine, which has a generator in a pressurized crankcase, is suitable for an application of a generator set. Because the hermetic engine does not have any external seal device between the working space and the atmosphere, and it expects to have small mechanical loss. Then we remodel the original Stirling engine to the hermetic structure. Also, in order to reduce the mechanical loss, the shot peening of molybdenum-disulfuride, which is one of the surface treatments, is applied to the cylinder wall, a surface of the displacer rod and other mechanical parts. And, the performance of the engine is measured for a comparison with that of the original engine. As the result, it is confirmed that the hermetic engine has higher shaft power and generator power than that of the original engine.

INTRODUCTION

Recently, co-generation systems and heat recovery systems with Stirling engines have been developing in the world. Many of these Stirling engines drive a generator. When we aim to get a high performance Stirling engine generator, it is considered that a hermetic structure, whose generator is located in a crankcase, is very effective.

On the other hand, we have been developing the experimental Stirling engine named Ecoboy-SCM81 (Fig. 1) since 1995. It was designed and developed in a RC127 committee of Japan Society of Mechanical Engineers on 1995 [1]. After several experimental developments, it reached the target shaft power of 100 W. Also the experimental results have been useful for developments a simulation model for compact Stirling engines [2].

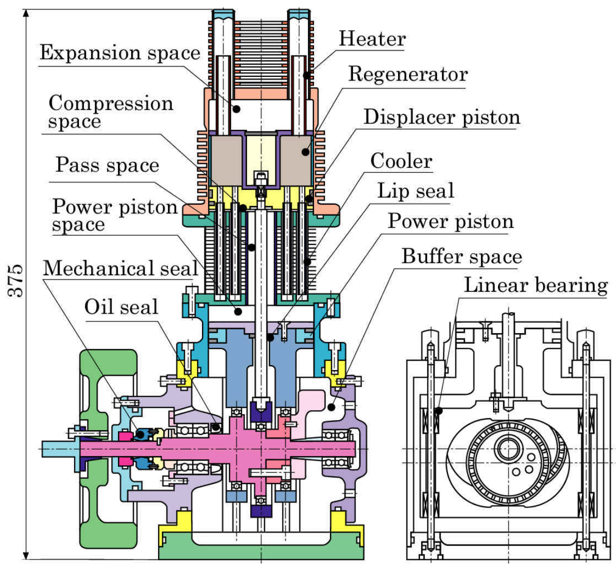


Fig. 1, Schematic view of Ecoboy-SCM81 (1995)

The original engine had a mechanical seal as an external seal device. In this paper, we remodel the engine to the hermetic structure. Also, a shot peening with molybdenum-disulfuride, which is one of the surface treatments, is applied to the cylinder wall, a surface of the displacer rod and other mechanical parts. And the performance of the engine is measured for a comparison with that of the original engine.

REMODELLING OF THE EXPERIMENTAL STIRLING ENGINE

Structure of the Original Engine

Figure 1 shows a structure of the original engine, and Table 1 lists the specifications and target performance of the engine. The engine contains unique features, including special heat exchangers named moving-tube-type. Also, a displacer piston has both heating and cooling inner tubes for the working gas. A regenerator is located in the displacer piston. A Scotch-yoke mechanism is applied as a piston drive mechanism. The mechanism was considered that it has a small mechanical loss and it bring a compact size. The original engine has a mechanical seal as an external seal device between the working space and the atmosphere. In the operation, a generator is attached to the output shaft.

Table 1, Specifications and target performance

Engine type	Improved Gamma-type
Working gas	Helium
Maximum pressure	1.1 MPa
Heater wall temperature	750 deg C
Compression space gas temperature	40 deg C (Water cooling)
Rated engine speed	1000 rpm
Bore x Stroke	72 mm x 20 mm
Output power	100 W
Net thermal efficiency	20 %

Hermetic Structure

As factors of the mechanical loss of the original engine, there are piston rings, a lip seal, an oil seal, a mechanical seal and bearings. Figure 2 shows the contents of the mechanical loss by a simulation model [(2)]. When the engine is remodeled to the hermetic structure, the mechanical seal and the oil seal, which keeps the lubricant oil for the mechanical seal, can be omitted. From this figure, It is expected that the mechanical loss of the hermetic engine can be reduced about 20 W at the mean pressure, P_m = 0.8 MPa and the engine speed, N = 1000 rpm. In the case of a compact Stirling engine, the rate of the mechanical loss the external seal device is very high.

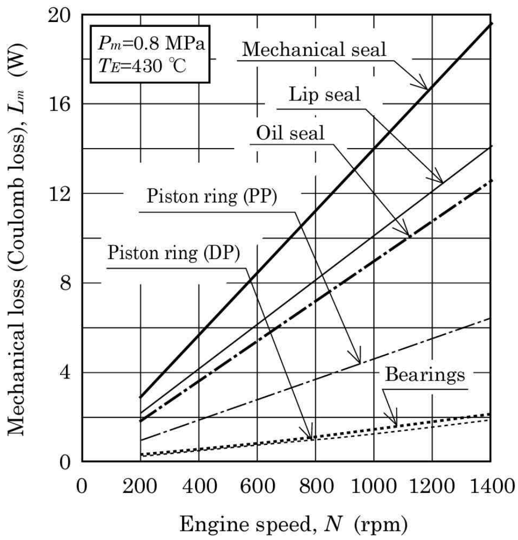


Fig. 2, Calculated results of mechanical loss

The engine has a pressurized crankcase, and the piston drive mechanism is supported by sealed-bearings. Then it is easy to remodel to the hermetic structure. Figure 3 shows a structure of the hermetic engine. The generator is located in the pressurized crankcase.

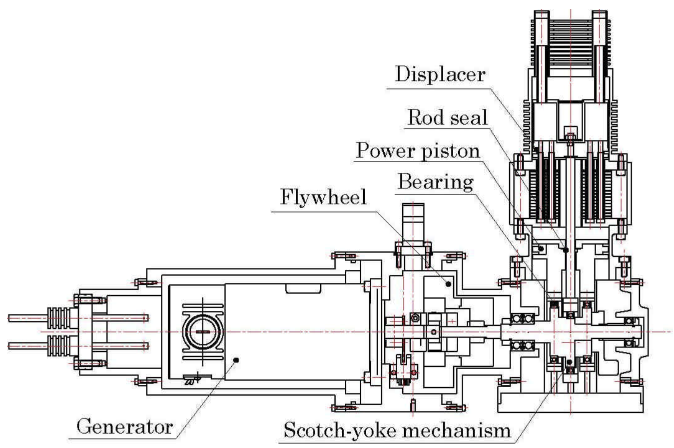


Fig. 3, The Ecoboy-SCM81 with the hermetic structure

Shot Peening of Molybdenum-Disulfuride Compounds

The shot peening of molybdenum-disulfuride is one of the surface treatments for reducing of the friction loss. The molybdenum-disulfuride compounds are projected to the surface with high-speed compressed air. It has been confirmed that the shot peening reduces the mechanical loss of an internal combustion engine whose piston skirt is applied [3].

In order to investigate the effects of the shot peening, it is treated to the cylinders, the displacer rod and the other mechanical parts of the hermetic Stirling engine as shown in the Fig. 3.

EXPERIMENTAL CONDITIONS

Figure 4 shows an outline of the measuring system for the hermetic engine. An optical sensor is located in the pressurized crankcase, and it generates a pulse per one revolution. The indicated power is calculated in a personal computer based on the signals of the optical sensor and pressure sensors. But it is difficult to adjust the sensors. Then the measuring accuracy of the indicated power is very low. An electric load is connected to the generator. The hermetic engine does not have any torque measuring equipments, then the torque and the shaft power are lead from the results of the motoring tests for the generator.

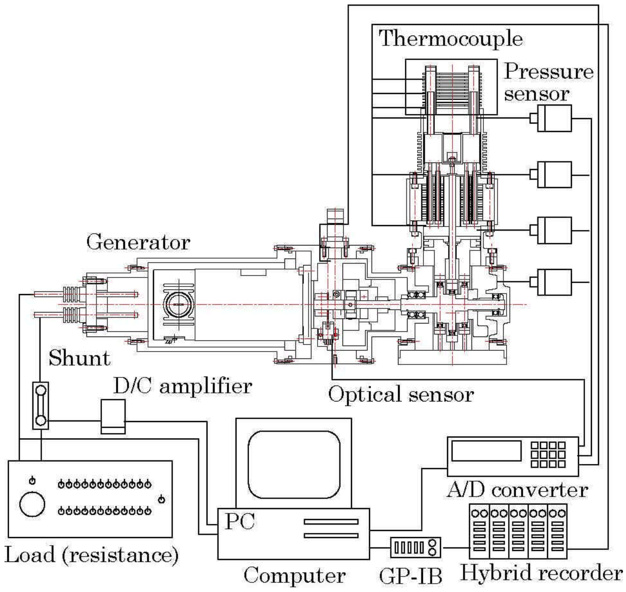


Fig. 4, Measuring system of the hermetic engine

Table 2 lists the experimental conditions. Table 2 (a) is the experimental condition to investigate the effects of the hermetic structure and the shot peening. Helium gas, whose mean pressure, P_m is 0.4, 0.6 and 0.8 MPa, is used as the working gas. And the heat input to the electric heater is adjusted to keep the expansion gas temperature, T_E = 490 deg C. The experimental results are compared with that of the original engine, which has the mechanical seal [4]. Moreover, the coolant temperature in the experiment of the hermetic engine is higher 10 deg C approximately than that of the original engine, so it is difficult to estimate the performance strictly. Table 2 (b) is the experiment to find the maximum performance of the recent engine. The mean pressure is set to 0.9 MPa. And the heat input of the electric heater is kept to 1.1 kW, that is the limit of the electric heater.

Table 2, Experimental conditions

(a) Comparison with hermetic and original type

Heat source	Electric heater
Expansion space gas temp, T_E	490 deg C
Working gas	Helium
Mean pressure, P_m	0.4, 0.6, 0.8 MPa
Cooling type	Water cooling
Cooling water flux	2-2.5 L/min [3 L/min (1997)]
Cooling water inlet temp.	20-22 deg C [12 deg C (1997)]
Engine speed, N	500~1600 rpm

(b) Maximum performance

Heat source	Electric heater
Total heat input, Q_{in}	1.1 kW (110 V x 10 A)
Working gas	Helium
Mean pressure, P_m	0.9 MPa
Cooling type	Water cooling
Cooling water flux	2.5 L/min
Cooling water inlet temp.	20 deg C
Engine speed, N	1200~1700 rpm

PERFORMANCE OF THE EXPERIMENTAL STIRLING ENGINE

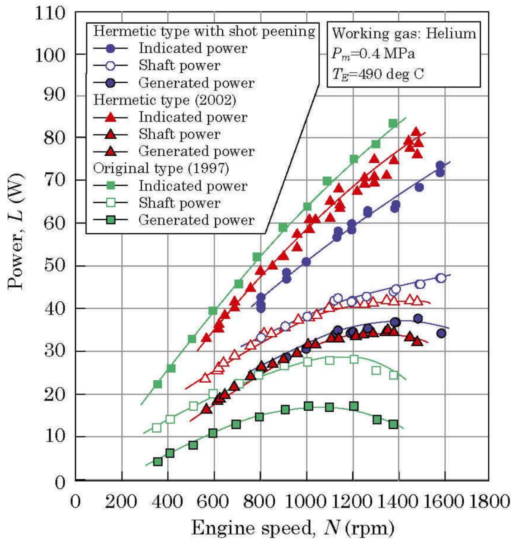
Effects of Hermetic Structure and Shot Peening

Figure 5 shows the relation between the engine speed and the power at the experimental condition of Table 2 (a). From the figure, the indicated power of the hermetic engine is lower than that of the original engine. It is considered that the effect of the compression space gas temperature and the deterioration of PTFE seal devices appeared strongly. The shaft power and generated power of the hermetic engine is very higher than that of the original engine. Especially, in the case of the lower pressure condition, the rate of the increasing becomes high. As described above, the measuring accuracy of the indicated power of the hermetic engine is low. Then we cannot estimate the mechanical loss suitably. But we can see that the reduction of the mechanical loss agrees with the estimated result of Fig. 3 approximately. From these experiments, it is confirmed that a compact Stirling engine generator needs the hermetic structure for getting the high performance.

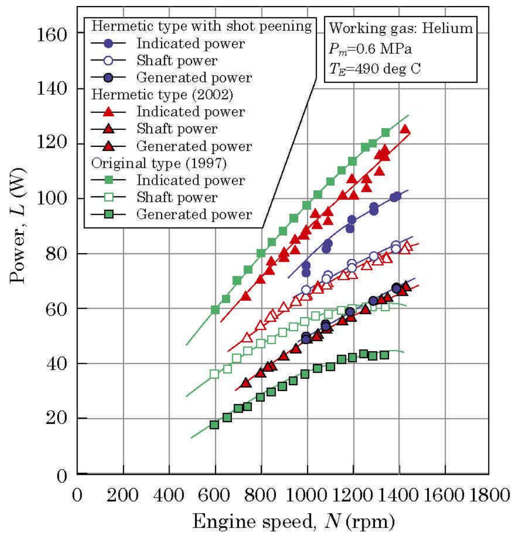
On the other hand, the shaft power of the hermetic engine with the shot peening is somewhat higher than that of the engine without the shot peening at the higher engine speed range. It is difficult to estimate the effect of the shot peening from these results. Because when the engine was applied the shot peening, several mechanical parts of the Scotch-yoke mechanism were changed. It is considered that the shot peening is effective to the reduction of the mechanical loss and the long-life operation for the sealing and moving devices. A component test or a long-time operation is needed for the detailed estimation of the effects.

The Maximum Performance

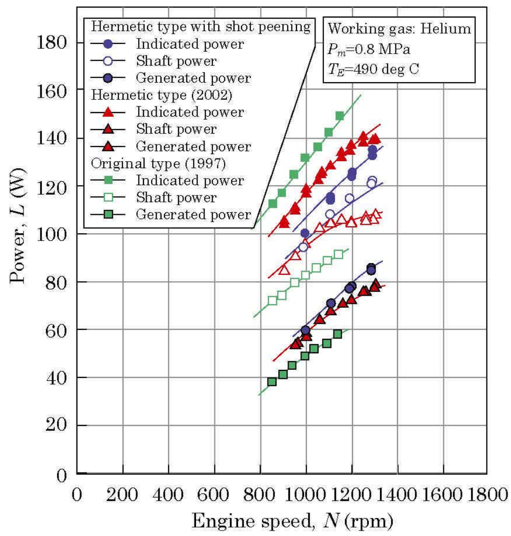
Figure 6 shows the experimental results of the power and temperature at the experimental condition of Table 2 (b). They are the results of the hermetic engine with the shot peening. From the figure the maximum generated power is 95 W at the engine speed, N = 1485 rpm and the expansion space gas temperature, T_E = 437 deg C. In the same time, the indicated power, L_i is 149 W, and the shaft



(a) Mean pressure, P_m=0.4 MPa



(b) Mean pressure, P_m=0.6 MPa



(c) Mean pressure, P_m=0.8 MPa

Fig. 5, Experimental results

power, L_s is 131 W, though they have low measuring accuracy. The mechanical efficiency (=L_s/L_i) is calculated over 80 %. As the mechanical efficiency of the original engine was about 60-65 %, the hermetic structure and the shot peening are affected to reduce the mechanical loss strongly.

Figure 7 shows the energy balance at the maximum generated power condition. In the figure, the total input, Q_{in} is the heat energy to the electric heater. The heat input, Q_h is calculated from the rejected heat to the cooling water, Q_{rej} and the indicated power, L_i. The total efficiency (=L_g/Q_{in}) is about 8.3 %. This value is not high as a Stirling engine generator. The engine has the large heat conduction loss, Q_{cond} and the heat source loss, L_b. For getting the higher efficiency, the insulate structure of the cylinder wall is needed to reduce the heat losses. Also, it is important to increase the internal conversion efficiency (=L_i/L_E) of the Stirling engine with increasing the expansion space gas temperature, T_E.

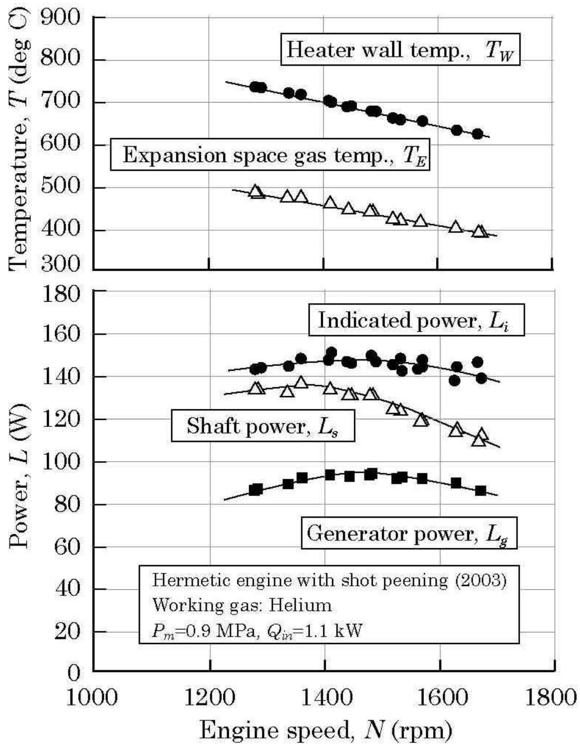


Fig. 6, The maximum performance

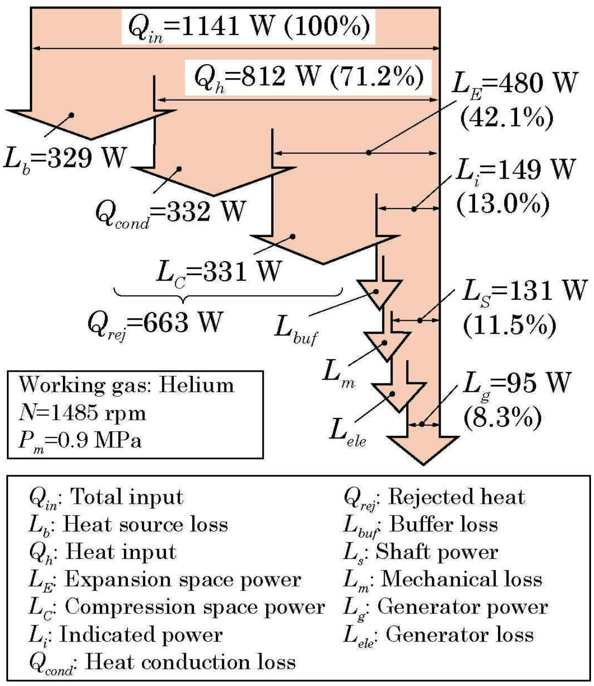


Fig. 7, Energy balance

CONCLUSION

The summary of the results is shown below.

(1) A compact Stirling engine has a large mechanical loss at the external seal devices. Then the hermetic structure is effective to reduce the mechanical loss.

(2) The shot peening of molybdenum -disulfuride is effective to reduce of the mechanical loss at the higher engine speed range.

From the experiments, we confirmed that a compact Stirling engine with the hermetic structure has high performance, and the shot peening of molybdenum-disulfuride is effective to reduce of the mechanical loss. The measured data does not have high accuracy. Then it is difficult to estimate the mechanical loss in detail. However we are sure that these results will contribute to developments of new Stirling engines.

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