

Investigation on Solar-Powered Low-Temperature Stirling Motor

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ABSTRACT: The article researches the design, manufacture and testing of solar-powered low-temperature Stirling motors version V in tropical climate. The author changes some parts of the engine to improve performance and simultaneously measures the engine's performance during the day under solar radiation. This engine is connected to a water pump to provide clean water to households. This solar-powered low-temperature Stirling motor is a part of the solar hot water and cooling supply system for household that the author researched.

KEYWORDS: Solar energy, Stirling motor, low-temperature Stirling motor, solar-powered, Stirling V.

I. INTRODUCTION

Low-temperature Stirling engines represent a special development direction. They operate at up to a maximum of 150°C, and enable the use of waste heat and solar radiation energy. The first low-temperature Stirling engine was developed in 1983 by Professor Kolin at the University of Zagreb [1,2]. Since the volume-related output is very small for these engines, low-temperature Stirling engines are currently used mainly as demonstration units. In 2001, a usable solar low-temperature Stirling engine capable of driving a water pump was developed by Mr. Eickhoff, J. under Prof. J. Knorr at the University of Dresden [3].

Afterwards, Mr. Chen's solar Stirling engine was also used by Mr. Chen. Prof. Knorr further developed [4]. He has built a new Stirling engine with a new design. The advantages of this Stirling engine are simpler manufacture, good sealing and lower cold-gas temperature. Within the scope of the project contract between the TU Dresden and the University of Danang, Prof. Knorr was given the version III of the Stirling engine (Version Eickhoff) from Germany to Danang and tried in the field test. After many experimental investigations, a new version of the Stirling engine built was developed, manufactured and tested in Vietnam by Mr. Chen. It is referred to as version V in this work.

II. CONSTRUCTION OF VERSION V OF THE SOLAR STIRLING ENGINE

II.1 Construction of version IV

The solar low-temperature Stirling engine IV consists of the following essential components: absorber, body, displacer, regenerator, cooler and working piston as shown in Fig. 1.

The absorber absorbs the solar energy and converts it into heat. The heat is transferred to the working gas in the Stirling engine. The displacer with the membrane divides the closed space of the Stirling engine into two spaces: hot side above and cold side below. The displacer moves the working gas from the hot side through the regenerator to the cold side and vice versa. The cooler consists of two aluminum satellite dishes, between which the cooling water flows to dissipate the heat from the working gas from the Stirling engine. The body is a large ring made of plastic PPS to ensure thermal insulation. The absorber is a simple satellite dish that is top coated with a selective foil or painted with solar paint to better absorb solar radiation. The working piston is designed as a bellows made of rubber fabric. The engine is a crank mechanism consisting of connecting rod and flywheel[5,6].

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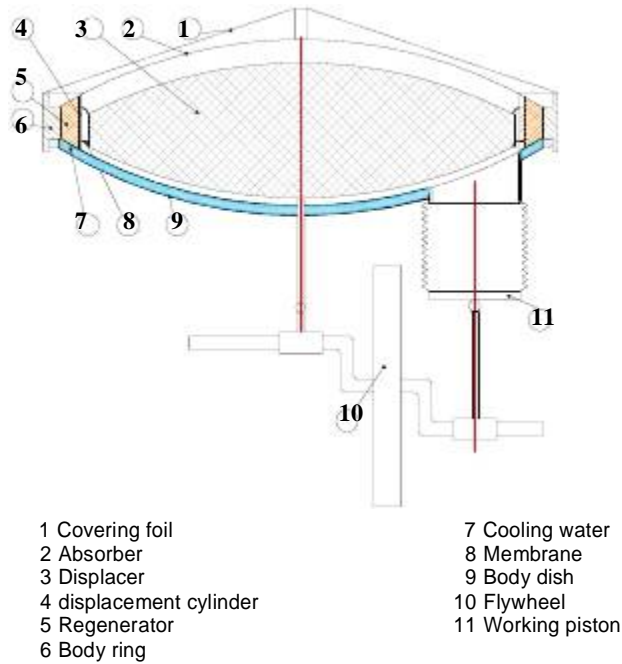


Fig. 1 Structure of the solar-powered low-temperature Stirling engine IV [4]

II.2 Construction and production of the Stirling engine V

The solar Stirling engine V is a further development of the Stirling engine IV as shown in Fig. 2.

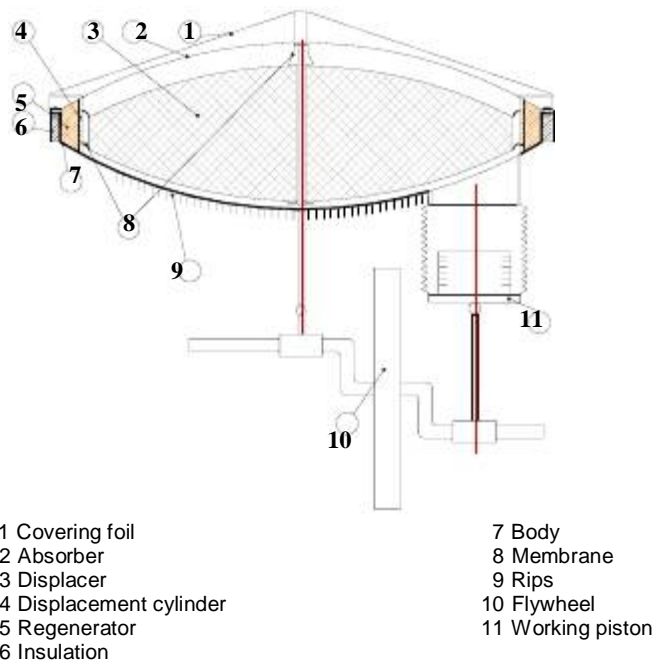


Fig. 2 Structure of the solar-powered low-temperature Stirling engine V

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In comparison with the Stirling engine IV, the components body, radiator, displacer and working piston have been changed (Fig. 3). The absorber is made of steel as large aluminum satellite dishes are not available in Vietnam. However, aluminum has better thermal conductivity than steel. The absorber surface absorbs the solar radiation and is coated with a selective foil. Due to the selected form of the absorber, it is stable against pressure in the Stirling engine. The body is made of steel and insulated so as not to lose heat to the environment (Fig. 2 and Fig. 3).



Fig. 3 The Stirling engine V during the test

The heat dissipation is ensured in the Stirling engine by the radiator. Opposite the Stirling engine IV of the Stirling engine V is operated with air as a coolant. Therefore, the cooler consists essentially of steel ribs, which have a width of about 20 mm and a thickness of 1 mm and are welded from below to the body in a circular shape (Fig. 4) [7,8].



Fig. 4 Ribs welded to the body from below

The mechanical work of the Stirling engine is dissipated by the working piston. In comparison with the Stirling engine IV, the working piston consists of a bellows and a steel pot with ribs, which reduces the dead volume in the Stirling engine and additionally emits heat from the working gas to the environment (Fig. 5.). The bellows is made of CSM rubber fabric and has two cuffs, which are firmly connected to both the body and the steel pot. The bellows has an outer diameter of 325 mm and a wall thickness of 1.5 mm and an extended length of 455 mm. It was supplied by the German company Möllerbalg. The other components were made in the workshop [7,9,10].

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Fig. 5 Working piston

The displacer is made according to the shape of absorber and body made of heat-insulating foam. Opposite the Stirling engine IV, a membrane is inserted in the center of the displacer at the top (Fig. 6).



Fig. 6 Displacer with membrane

This ensures that the working gas does not flow through the central guide of the displacer when the displacer moves the working gas from the hot side to the cold side and vice versa. Thus, there is no flow loss of the working gas between hot and cold side. In addition, the central guide was redesigned to move the displacer easier and more stable. The changes to the Stirling engine V compared to IV are summarized in Table 1.

Components	Stirling motor IV	Stirling motor V
Cooling	Water (cooling area between two satellite dishes)	Air (steel ribs under body)
Body	Polyphenylsulfide (PPS) ring and Aluminum satellite dish	Steel satellite dish
Working piston	Bellows and plastic disc	Bellows and steel dome with ribs
Displacer	foam	Foam with membrane

Table 1 Comparison between Stirling engine IV and V

Air cooling has the great advantage that the Stirling engine does not need cold water to dissipate heat during operation. Thus, no pressure loss occurs as in the version IV with surface cooling and the useful power of the pump increases. The diaphragm mounted on the displacer enhances the effect of the compression and the expansion process and thus increases the performance of the Stirling engine. With the new central guide, the displacer can be moved more easily and stably and therefore the mechanical friction loss is reduced. The body ring was made of steel, i.e. it is stable and

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dense. Plus, it's cheaper than an aluminum case. The working piston with steel pot is stable, easy to manufacture and the dead volume in the Stirling engine can be reduced.

But the Stirling engine V also has some disadvantages. Since it is cooled with air, the temperature of the working gas is slightly higher on the cold side. To eliminate this problem, more ribs must be welded to the body and also into the working piston. In addition, because of the use of steel for the outer components such as body, absorber, ribs, piston, the Stirling engine is not so stable against corrosion. Therefore, these components must be well painted against rust, but this negatively affects the heat transfer.

III. EXPERIMENTAL INVESTIGATION OF THE STIRLING ENGINE V

The Stirling engine V was taken after production at The University of Danang in operation and examined his performance. He was good and calm. During the day, it can be started around 8.30 am and stop slowly at about 3.30 pm. With the driven pump about 300 liters of water per hour were conveyed to 5 m height, the speed was at about 25 to 35 rpm.

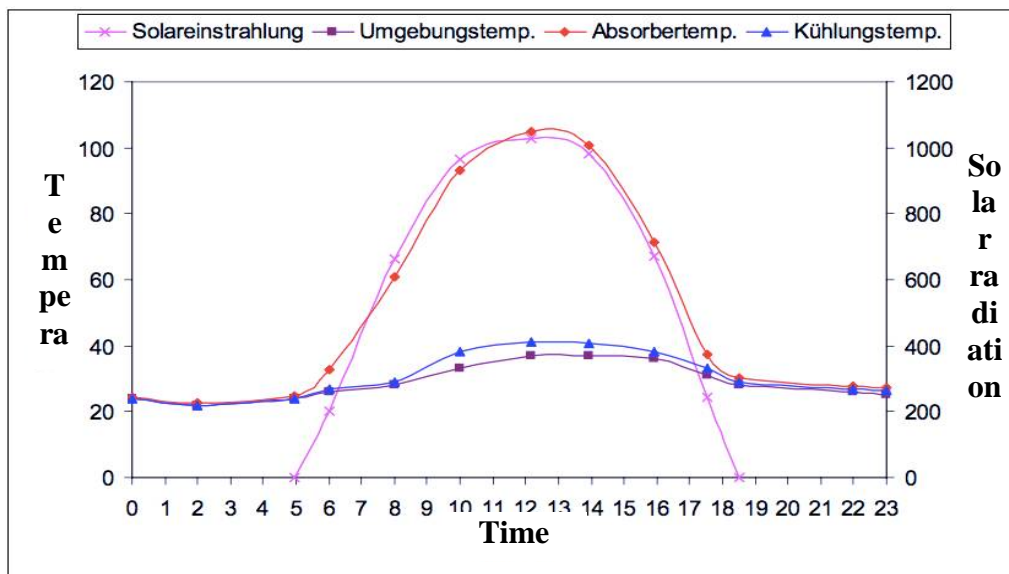


Fig. 7 Solar irradiation and temperature curves (Stirling engine V)

With the solar Stirling engine, the temperature difference between the hot side and the cold side is very important. If this temperature difference is large, the performance increases and the functionality improves. Two temperature measuring devices are used in Stirling engine to determine the two temperatures. One is located at the top of the absorber and one at the bottom of the body.

Both temperatures and ambient temperature are shown in Fig. 7. In addition, a curve of solar radiation is registered at the Danang site. The solar irradiation was determined with the help of the solar measuring device MacSolar SLM018c-2 of the company SolarCosa Berlin. The average solar radiation in the summer in Danang is more than 880 W/m² [7].

The absorber temperature rises from the sun rise and reaches the maximum value of about 105°C at 12.30. After that, it sinks to around 68°C until around 16.00, causing the Stirling engine to slow down and finally come to a standstill. The temperature on the cold side is about 4 to 5°C higher than the ambient temperature during the operating time of the Stirling engine. In the experiment, the Stirling engine ran under load of the driven pump when the temperature difference between the hot and cold sides was about 35°C.

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IV. CONCLUSION

The solar Stirling engine enables an effective use of solar energy in Vietnam. This is especially true in the countryside, where there is an acute shortage of electricity. Based on the literature and the experiments, the Stirling engine V was manufactured. The production is simple; except for the bellows, all parts can be made in Vietnam.

Experiments have proven the stable operation of the engine.

To optimize the performance of the Stirling engine, the effects of phase angle, compression ratio and heat losses through convection and emission were investigated. In addition, mechanical losses and dead volumes were reduced and the heat transfer through the absorber improved.

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