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PERSPECTIVES ON MICROCOGENERATION OF HEAT AND POWER USING FREE PISTON STIRLING ENGINES

BY
*C. A. HOMUTESCU, *D. DRAGOMIR - STANCIU,
*V. M. HOMUTESCU and *A. HOMUTESCU

Abstract. The work presents the employment of a free piston Stirling engine in the cogeneration of heat and power needed by a household. The cyclic evolution of the free piston Stirling engine is described and his advantages both as combustion engine engaging in motion an electric generator and as warm gas generator for hot water production as well.

Keywords: free piston Stirling engine, microcogeneration, heat, power.

1. Introduction

Invented in 1816 by the Scotsman Robert Stirling, the combustion engines running on a two isothermal and two isochoric process cycle were widely known and employed, especially in the United States and Great Britain, throughout the 19th century by mainly at the beginning of the 20th. The internal combustion engine apparition led to a popularity decrease for the STIRLING ENGINES that ended up almost completely forgotten.

The revival from decline took place in the second half of the 20th century. Benefiting of new materials and new manufacturing techniques, a new generation of SE emerged: SE for cars and buses, stationary solar SE, SE using the solar energy or isotope warm sources for space flights or purposes on other planets. Even thou in the road transport domain the SE are maybe overrun by the direct injection fed and catalytic converter equipped internal combustion engines, there are plenty of domains left where SE are attractive for sure.

Between the advantages let us mention that SE can run on any heat source (being in good sooth a multifuel power device), cause less pollution (due to the combustion taking place outside the cylinder), less noise and less vibrations, their efficiency reaching 40%.

Of all the numerous configurations of the SE, a distinguished pattern is the FREE PISTON STIRLING ENGINE invented by professor William T. Beale in the seventh decennium of the 20th century. The Beale engine does not own a drive to convert the reciprocating movement of the pistons into a rotary movement. The Beale engine is fit to be linked to reciprocating movement generator machines as the heat pumps (configuration that results into a pollution free refrigeration unit - no chlorofluorocarbonates) and as the alternators [1], [2]. The FPSE can work in any position and start without any external intervention being required.

2. Construction And Functioning Of The Free Piston Stirling Engine

A FPSE (fig. 1) has three main constructive components: cylinder 1 (hermetically sealed at both ends), power piston (usually called just piston) 7 - heavy- and the displacer piston (usually called just displacer) - light. The displacer is fit to the relatively wide diameter stem 5 which pierces inside the piston body.

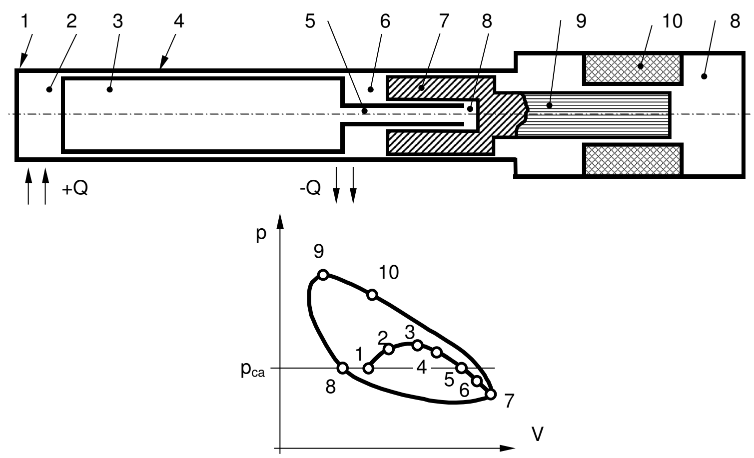

Fig. 1.- Schematic diagram of a free piston Stirling engine and its indicator diagram: 1 - cylinder; 2 - expansion chamber; 3 - displacer; 4 - regenerator; 5 - displacer stem; 6 - compression chamber; 7 - piston; 8 - gas springs; 9 - magnet; 10 - electrical coil

The pistons confine three chambers inside the cylinder: the expansion chamber (warm chamber) 2, the compression chamber (cold chamber) 6 and the gas springs 8 located under the piston and under the displacer stem. The displacer stem 5 is built as a tube open at both ends, so that the interior space of the displacer communicates with the gas spring spaces as a component part of them. The active space of the Beale engine is composed of the compression chamber 6 and the expansion space 2. Between the cylinder and the displacer there is a free space 4, shaped like a long thin tube, which plays the role of heat regenerator. Through this space the communication between the compression chamber and the expansion chamber is accomplished. The expansion chamber 2 is equipped with a heating system while the compression chamber is fitted with a cooling system (elements not pictured on fig. 1).

The functional model presented implies that no gas amounts can pass in any direction through the spaces between the piston and the cylinder on one hand and between the piston and the stem on the other hand. Initially, the engine rests in an inactive state during which the pistons lie at a certain distance apart, positions obtained simultaneously with the engine stopping and as a result of the force equilibrium established then but also on geometric grounds. It is admitted that the working fluid pressure is the same inside all chambers and equal to the pressure p_{gs} inside the gas spring space; the temperature is also the same everywhere and equal to the atmospheric temperature. The initial state is represented on fig. 1 by point 1. As the working space warms up, temperature and pressure inside the working space start to grow, the process corresponding on fig. 1 to the curve 1-2. The pressure increase forces both pistons to begin displacing towards the right end, the displacement causing the working space volume growth. A simplifying hypothesis is made, according to which the gas spring space pressure p_{gs} remains constant at all times.

The two pistons advance towards the right end through an accelerated movement caused by the pressure forces exercised by the working fluid. The piston acceleration ratio will be

$$\frac{a_P}{a_D} = \frac{(p - p_{gs})A_C / m_D}{(p - p_{gs})(A_P - A_C)/m_P} = \frac{1}{A_P / A_C - 1}\,\frac{m_P}{m_D}\,, \qquad (1)$$

where a_P and a_D are the piston and displacer accelerations, A_P is the frontal area of the piston, A_C is the displacer stem cross area, p is the current pressure inside the working space and p_{gs} is the gas spring space pressure.

If through the engine design the ratios $m_P / m_D \approx 10$ and $A_P / A_C \approx 4$ are acquired, then it comes out that the acceleration ratio $a_P / a_D > 1$, meaning that the displacer moves faster than the piston. As a consequence, the working fluid is displaced from the compression to the expansion chamber. The process hastens both on the grounds of the pressure increase inside the working space (whereas the pressure p_{gs} corresponding to the gas spring maintains practically constant) and of the acceleration increase that the piston and the displacer undergo. The displacement of the working fluid from the compression to the expansion chamber ceases when the piston and displacer touch each other, that will be the point 3 on fig. 1. From this moment on the two parts move together. At a given time the influence the expansion chamber volume increase has will overcome the influence of the heat conveyed to the agent and then the pressure inside the working space of the engine will start to drop. In the thermodynamic state 4 the pressure inside the working space is still greater than the gas spring pressure ($p > p_{gs}$), the expansion chamber volume keeping on increasing until the state marked by point 5 is reached, state that acknowledges the equalization of the pressures inside the working space and the gas spring. Because of the pistons' inertia (the properly called piston and the displacer), the working space pressure drops below the gas spring pressure as the movement continues. As a result, the ensuing pressure forces that act over the pistons change orientation and the pistons' movement becomes decelerated. Having a lighter body, the displacer is the first to respond to this signal and slows down more promptly, detaching from the contact with the piston which keeps heading right. That's the time when the working fluid inside the expansion chamber starts its displacement through the regenerator to the compression chamber. Consequently to a certain amount of gas being conveyed from the expansion to the compression chamber the pressure inside the working space drops, so that the difference (p_{gs}-p) rises rapidly. The pressure drops fast because on one hand the working space volume keeps on growing and on the other the gas already in the compression chamber cools down. Due to its small mass and to the growing on pressure difference, the displacer is the first to stop - state 7 on fig. 1, and just afterwards accelerates toward the somehow improperly called cylinder head. The displacer reaches quickly the so called cylinder head and maintains that position as long as the difference (p_{gs} - p) is above zero. At a given moment, represented by state 7, the piston motion ceases and this working part starts heading back from where it came under the influence of the gas spring pushing it backwards, upon the comeback the gas spring pressure being greater than the working space pressure. All this time the working fluid is being compressed; when state 8 is reached, the pressures are leveled ($p = p_{gs}$). Then, pressure inside the working space is greater than inside the gas spring. Consequently, the displacer starts moving right until contact with the piston is accomplished - state 9. During the piston and displacer common displacement, the agent inside the warm (expansion) chamber expands, the process being represented by the curve 9-10-7 which concludes the cycle. The cycle recommences again, without the starting succession 1-2-3-4-5-6-7. It must be pointed out that the previously shown schematic diagram (implying both starting and functioning) is but a simplified one, in fact several cycles being necessary for the engine to operate steadily in the regular way. The yielded work produced by the FPSE is used to drive an alternator. To achieve this the piston has a magnet attached to it that reciprocates through the electrical coil 10.

3. A Power And Heat Microcogeneration Installation Using The FPSE

According to the schematic diagram on fig. 2, the SE 11 receives heat from a burning chamber inside which, in principle, anything can be burnt, that including classic fuels and vegetal wastes like corncobs, sawdust, cereal husks, cotton waste and bagasse, situation when the exhaust dries them previously inside the fuel predryer 6. Once removed, the exhaust gases heat the agent inside the heat exchanger 9 (the agent being water delivered by the circulation pump 13). The heated agent feeds the heat consumers 12. The SE drives the alternator

14, the power produced being converted to direct current by the charger 15 connected to the battery 2. The inverter 17 provides the consumers with alternative current even when the SE is rests.

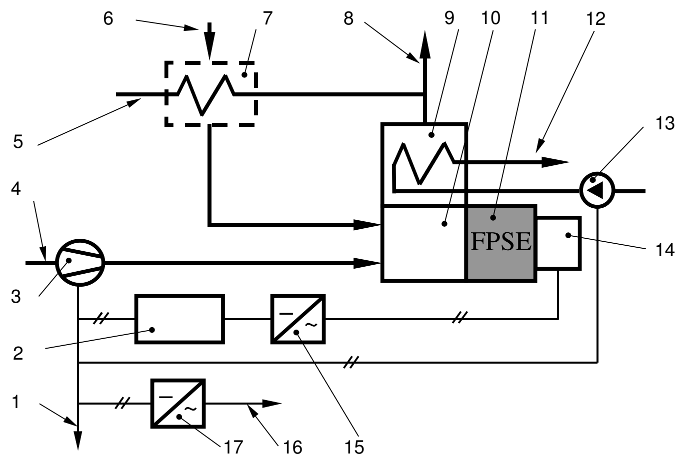

Fig. 2.- Schematic diagram of a power and heat microcogeneration installation using FPSE: 1 - DC consumers; 2 - battery; 3 - blower; 4 - air inlet; 5 and 8 - exhaust outlet; 6 - feeding system; 7 - predryer; 9 - heat exchanger; 10 - burning chamber; 11 - FPSE; 12 - heat consumer; 13 - circulation pump; 14 - alternator; 15 - charger; 16 - AC consumers; 17 - inverter

4. Using Stirling Microcogeneration inside a Household

Covering the daily heat and power dwelling consumption of a household situated some place inside the temperate climate areas (where the mean winter temperature varies around -5 ... +3˚C) can be a job fit for Stirling microcogeneration installations, as seen on fig. 3.

The Stirling microcogeneration installation works intermittently, the pace being imposed by the comfort necessities of the respective household. The exceeding power produced can be stored by the battery or can be sent in the local network (that if the laws concerning electrical power set rules to manage the matter). The Stirling microcogeneration installations fit for domestic purposes must cover a power load up to 3 kW and a thermal power load of about 6 ... 10 kW. Such installations are already on sale [2].

5. Conclusions

Using the FPSE microcogeneration installations instead of the plain individual heating installations assures a superior and complete employment of the heat liberated upon fuel combustion.

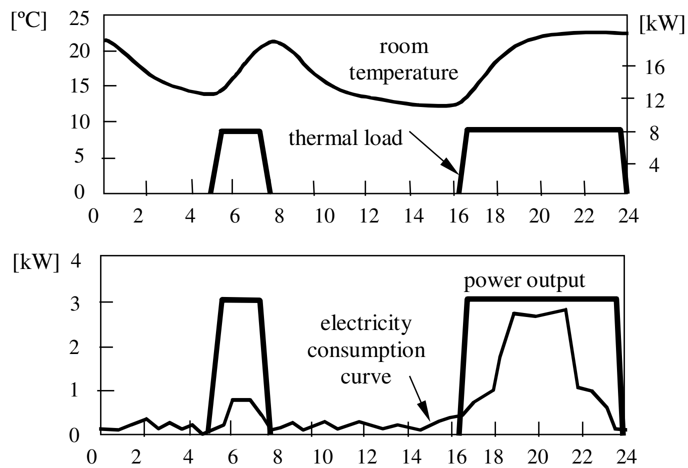

Fig. 3.- How the microcogeneration installation works

Harnessing the SE leads to advantages like multifuel versatility, low noise and low emissions and makes the SE microcogeneration installations ideal for individual abodes both from urban or remote locations.

*“Gheorghe Asachi” Technical University, Department of Thermal Machines, Iaşi, Romania.

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PERSPECTIVELE MICROCOGENERĂRII ENERGIEI ELECTRICE ŞI TERMICE CU MOTOARE STIRLING CU PISTOANE LIBERE
(Rezumat)

Se prezintă utilizarea motorului Stirling cu pistoane libere pentru cogenerarea energiei electrice şi termice necesare unei locuinţe. este descrisă funcţionarea ciclică a motorului Stirling cu pistoane libere şi sunt arătate avantajele sale în calitate de motor termic care antrenează un generator electric şi ca generator de gaze pentru producerea apei calde.