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COMPARATIVE STUDY OF STIRLING ENGINE

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***Abstract*—A Stirling engine is a heat engine operating by cycle compression and expansion of air or other gas stirling engine is a new generation of stirling engine that has been born to increase the effectiveness of stirling engine .this engine is noted for its high efficiency compared to another engines. This compatibility with alternative and renewable energy sources in which it has become increasingly significant as the price of conventional fuels rises, and also in light of concerns such as peak oil and climate change . this paper is mainly aimed to analyze stirling engine as a LTD or practical engine which has high efficiency almost nearer to the carnot cycle based engine .As a result , this study indicates how stirling engines work and give the higher efficiency than present time engine.**

***Index Terms*-- STIRLING, Isothermal, Efficiency, regenerator, R123.**

I. INTRODUCTION

In 1816 Stirling engine is invented by Robert Stirling.Until 1900s the Stirling is commercial success but brisk evolution of internal combustion engine and In starting of 1900th century electric motor stop the development of Stirling engine.But in the end of 19th century due to fuel calamity and increasing demand for vitality and increasing territory perturb a wide range examination in material technology have been made on the development of Stirling engine.In modern years researchers and mercantile companies have been showing engrossment in developing Stirling engine due to several reasons like that it's simplicity in construction,multi fuel capability,low noise,high heat efficiency and reliability.In addition,it can be used for applications in combined heat and power, heating and cooling,heat pump,low temperature difference engine and automotive, marine and aircraft engines

Fast development of industry has resulted in extensive use of fossil fuel for electricity and heat production. This in turn has caused serious environmental problems like global warming, ozone layer destruction, acid rain and contamination of lands and seas. These problems associated with use of fossil fuel have focused attention on new energy sources and on effective means of energy conversion and utilization. Use of renewable sources of energy such as solar energy, wind energy, biomass energy and geothermal energy as well as waste heat conversion are solutions to the problems caused by fossil fuel. The main drawbacks associated with the use of renewable sources of energy are lack of technology to efficiently convert the energies and high initial capital cost to install the conversion technologies

A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas at different temperatures, such that there is a net conversion of heat energy to mechanical work More specifically, the Stirling engine is a closed-cycle regenerative

heat engine with a permanently gaseous working fluid. Closed-cycle,in this context, means a thermodynamic cycle in which the working fluid specific type of internal heat exchanger and thermal store, known as the renerator The inclusion of a regenerator differentiates the Stirling engine from other closed cycle hot air engine.

II. LITERATURE REVIEW

A. Adrian Chmielewski∗, Robert Guminski, Stanisław Radkowski, Przemysław Szulim ′ Institute of Vehicles Faculty of Automotive and Construction Machinery Engineering Warsaw University of Technology, 84 Narbutta Street, 02-524 Warsaw, Poland

The first part of this paper presents the thermodynamic analysis for a microcogeneration system with the Stirling engine, for the most commonly used working gases, among others: helium, nitrogen, and air. The methods of regulating performance for the Stirling engine were depicted, among which the increase of gas pressure in the working chamber and rise in temperature of the upper heat source can be rated. The results of the experimental tests are shown: the influence of the rise in pressure and temperature on the working gases, which in this experiment were: helium, nitrogen, and air. The paper also focuses on maximum power flow. The tests were performed on a laboratory test stand with a single–action alpha type Stirling engine, located at the Faculty of Automotive and Construction Machinery Engineering, Warsaw University of Technology, at the Integrated Laboratory of the Mechatronic Systems of Vehicles and Construction Machinery. In the second part of the paper the authors presented the power flow in a hybrid system (Senkey diagram) on the internal combustion engine with the Stirling engine, which is employed as a microco generation device of distributed generation. It enables high-temperature waste heat to be transformed into mechanical work and transition of mechanical work into electric energy with the help of an electrical appliance, for possible sale to the mains. While analyzing the power flow in the hybrid cogeneration system, attention was paid to low-temperature heat which can be utilized through electrical thermogenerators, among other things. The proposed microgeneration assembly (Stirling engine and electrical thermogenerators) could be used to recover energy from waste heat produced by the combustion engine during combustion of landfill biogas. The influence of microcogeneration systems on boosting the general efficiency of the combustion engine was taken into consideration in this work. The paper presents test results of combustion gas temperatures in the exhaust system of the combustion engine fuelled by biogas, at full-load conditions. Various limitations of the Stirling engine build are discussed, in the context of cooperation with the combustion engine and the use of waste gases as a high-temperature heat source.

B. Iván Mesonero Dávila, Susana López Perez, Cristóbal Villasante, A STIRLING ENGINE FOR THE 21ST CENTURY

The invention of the closed cycle heat engine by the Scotsman, Reverend Robert Stirling, in the 19thcentury was a momentous event in the history of engineering. By the mid-twentieth century, the Stirling engine had been resurrected out of obscurity and was playing a critical role in energy efficiency. The success of the Stirling engine can be attributed to its high thermal efficiency (which exceeds that of the internal combustion engine, its greatest competitor) and its versatility in terms of potential energy sources. The revitalisation of the Stirling engine occurred at Philips Research Laboratories in Eindhoven (Holland) where dozens of Stirling engines were designed, manufactured and tested over a period of almost 40 years . The progress made by Philips undoubtedly served as a foundation upon which other developments were built. Some of these developments continue today thanks to the work of different licensee companies. A second resurgence of these engines has been in progress since the beginning of this century. The impetus for this development has been the need to get a reliable system able to convert solar energy into electrical energy with maximum performance. The emergence of small household co-generation systems, which are both silent and efficient and are predicted to become an indispensable appliance in modern life, has also motivated the development of Stirling engines. Despite the fact that valuable expertise has been developed over the past century but remains hidden away and may never be accessed, currently, there are many technological advances that could potentially be applied to reach the Stirling engine of the 21stcentury. . In this paper, we present examples of the applications of these advances and review the current status and future prospects of this extraordinary machine.

C. Analysis of Stirling engine and comparison with other technologies using low temperature heat sources Tamrat Abishu Gelu Instituto Superior Técnico, Lisbon, Portugal

In this study, the thermodynamic performance of two different low grade temperature heat conversion technologies: the Stirling engine and the Organic Rankine Cycle (ORC) are evaluated. The Stirling engine is studied using helium as a working gas for the conversion of low grade waste heat at 2500C into electricity. The effects of regenerator effectiveness, hot temperature and phase angle are studied. Thermal efficiency of 20.2 % is attained. The ORC is integrated with a solar thermal system to provide 2 kW of electricity. Six different organic working fluids are studied. Energy and exergy analysis is performed for each component of the ORC. Among the fluids studied, R123 and n-Pentane showed higher performance and thermal efficiency.

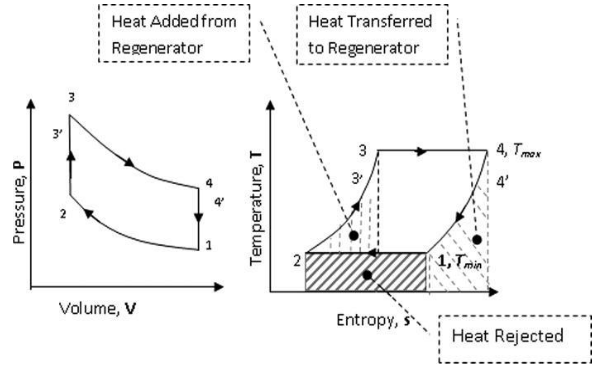
III. STIRLING CYCLE DESCRIPTION

The Stirling engine works on a closed regenerative thermodynamic cycle with external heat input between minimum and maximum temperatures, TC (Tmin) and TE (Tmax). It has three different configurations: alpha, beta and gamma. The three configurations are different in their mechanical design but their thermodynamic cycles are the same. The thermodynamic cycle in P-V and T-S diagram is shown in Fig.. To explain the working process of a Stirling engine, a representative diagram is shown in Fig.It has four processes namely isothermal compression and expansion and isochoric heat addition and rejection processes. The working fluid undergoes a cyclic compression and expansion process between the temperature limits so that there is a net conversion of heat to work or vice versa. The working process of a Stirling engine is explained below as given in. Consider a cylinder containing two opposed pistons with a regenerator between the pistons as shown in Fig.. The regenerator is like a thermal Fig. P-V and T-S diagram for Stirling cycle engine Fig. Stirling cycle engine. sponge alternatively absorbing and releasing heat, it is a matrix of finely divided metal in the form of wires or strips. The volume between regenerator and the right side piston is expansion volume and between regenrator and left side piston is compression volume. Expansion volume is maintained at high temperature and compression volume is maintained at low temperature. The temperature gradient of (Tmax-Tmin) between the ends of regenerator is maintained.

IV. ENGINE THERMODYNAMIC CYCLE (STIRLING ENGINE)

To start with a cycle we assume that the compression space piston, in Fig, is at outer dead point (at extreme right side) and the expansion space piston is at inner dead point close to regenerator. All working fluid is in the cold compression space. The compression volume is at maximum and the pressure and temperature are at their minimum values represented by point 1 on PV and TS diagram.

The four processes of the thermodynamic cycle are:



A P-V and T-S graph of the idealized Stirling cycle

Process 1–2: Isothermal compression process: During compression process from 1 to 2, compression piston moves towards regenerator while the expansion piston remains stationary. The working fluid is compressed in the compression space and the pressure increases from P1 to P2 . The temperature is maintained constant due to heat flow from cold space to surrounding. Work is done on the working fluid equal in magnitude to the heat rejected from the cycle. There is no change in internal energy and there is a decrease in entropy.

Process 2–3: Constant volume regenerative transfer process: In this process, both pistons move simultaneously, i.e. compression piston towards regenerator and expansion piston away from regenerator,so that the volume between pistons remains constant. The working fluid is transferred from compression volume to expansion volume through porous media regenerator. The temperature of working fluid increases from Tmin to Tmax by heat transfer from regenerator matrix to working fluid. The gradual increase in temperature of working fluid while passing through regenerator causes increase in pressure. No work is done and there is an increase in the entropy and internal energy of the working fluid.

Process 3–4: Isothermal expansion process: In this process, the expansion piston continues to move away from the regenerator towards outer dead piston while compression piston remains stationery at inner dead point adjacent to regenerator. As the expansion proceeds, the pressure decreases as volume increases. The temperature maintained constant by adding heat to the system from external source at Tmax . Work is done by the working fluid on piston equal in the magnitude to the heat supplied. There is no change in the internal energy, but an increase in the entropy of the working fluid.

Process 4–1: Constant volume regenerative transfer process: In this process, both pistons move simultaneously to transfer working fluid from expansion space to compression space through regenerator at constant volume. During the flow of working fluid through regenerator, the heat is transferred from the working fluid to the regenerator matrix reducing the temperature of working fluid to Tmin. No work is done; there is a decrease in the internal energy and the entropy of the working fluid interest as the core component of micro combined heat and power (CHP) units, in which it is more efficient and safer than a comparable steam engine. However, it has a low power-to-weight ratio rendering it more suitable for use in static installations where space and weight are not at a premium.

Efficiency of Stirling Engine

The mechanical work is

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$$\Delta W_{12} = -\int_{V_1}^{V_2} p(V)dV = -nRT_1 \ln\frac{V_2}{V_1}$$
$$\Delta W_{23} = \Delta W_{41} = 0$$
$$\Delta W_{34} = -nRT_3 \ln\frac{V_1}{V_2}$$

On the isothermal curves the change in inner energy $\Delta U = \Delta W + \Delta Q$ is zero.

$$\Delta Q_{12} = -\Delta W_{12} > 0$$
$$\Delta Q_{34} = -\Delta W_{34} < 0$$

On the isochoric (isovolumetric) curves the heat quantities are

$$\Delta Q_{23} = C_V(T_1 - T_3) < 0$$
$$\Delta Q_{41} = C_V(T_3 - T_1) > 0$$

The efficiency is then

$$\eta = \frac{-\Delta W}{\Delta Q}$$

ΔQ is the input heat, i.e. sum of all the heat quantities > 0:

$$\Delta Q = Q_{12} + Q_{41} = nRT_1 \ln\frac{V_2}{V_1} + C_V(T_3 + T_1)$$

ΔW is the total mechanical work:

$$\Delta W = W_{12} + \Delta W_{34} = -nR(T_3 - T_1)\ln\frac{V_2}{V_1}$$

So finally the efficiency is

$$\eta = \frac{T_3 - T_1}{T_3 + \frac{C_V(T_3 - T_1)}{nR \ln V_2/V_1}} < \eta_C.$$

It is smaller than the efficiency of the Carnot cycle. But it should be equal to it if all processes are done reversibly.

V. FUNTIONAL DESCRIPTION

In its simplest form a Stirling engine consists of a cylinder containing a gas, a piston and a displacer. The regenerator and a flywheel are other complimentary parts of the engine. When heat part of cylinder is heated up by an external heat source (figure2), the temperature rises and gas expands proportional in to the temperature of the heat side. Total volume is constant and limited by a piston thus expanded gas pushes the piston down, so the volume of the pressured gas is increased and the gas loses its pressure and temperature, then the piston backs to the heat side and compresses the gas by momentum force of the flywheel, when it reaches near its up limit the displacer also pushes the cooled gas to the heat side of the cylinder so that the gas is compressed and it can be prepared to do another cycle. The expanding gas pushes the piston down again to produce mechanical energy for doing work, this cycling will continue till an external heat source is available. The flywheel and the regenerator have great roles in the engine's performance. the flywheel converts the linear movement of a working piston to rotary movement, it gives needed momentum for the cycle procedure. Regenerator takes heat from gas in the expansion phase and releases heat to the gas in the compression phase,

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improving the engine's efficiency considerably. A Stirling engine and its components are shown in (figure2) below:

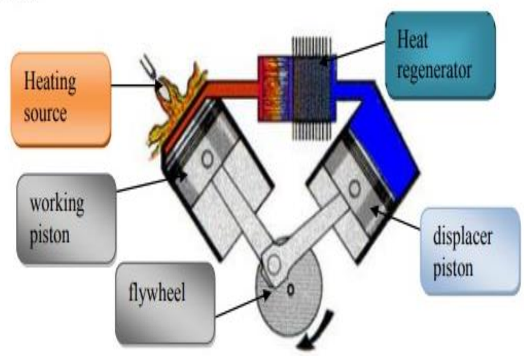

Figure 2 Stirling engine and its components

The cycle of a Stirling engine has four phases; heating, expansion, cooling and compression. Short explanation of each phase is given in the following:

· **Heating**: Heat source provides thermal energy to the engine so that it raises pressure and temperature of gas.

· **Expansion**: In this phase the volume increases, but the pressure and temperature decrease, mechanical energy is produced from heat energy during this phase of cycle only.

· **Cooling**: The gas is cooled and temperature and pressure decrease, so the gas is prepared to be compressed during this cycle.

· **Compression**: The pressure of gas increases whereas its volume decreases; a part of produced mechanical energy is used for processing of this phase, because it needs an amount of work to be done. The procedure of phase can be illustrated graphically in a PV diagram,

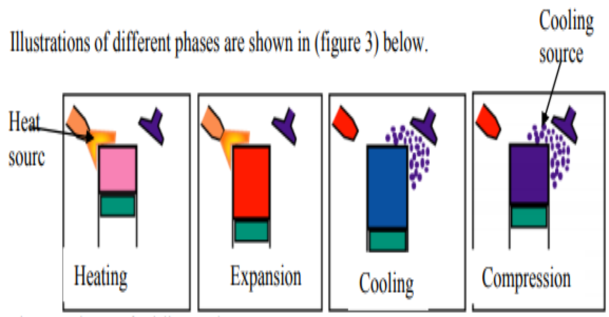

Figure 3 phases of Stirling cycle

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