Energy Conversion and Management 80 (2014) 357–362

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Comparison of the externally heated air valve engine and the helium Stirling engine

Zbyszko Kazimierski [a], Jerzy Wojewoda [b,*]

[a] Łódź University of Technology, Institute of Turbomachinery, Wólczańska 219, 90-924 Łódź, Poland
[b] Łódź University of Technology, Division of Dynamics, Stefanowskiego 1/15, 90-924 Łódź, Poland

ARTICLE INFO

Article history:
Received 13 March 2013
Accepted 26 December 2013
Available online 19 February 2014

Keywords:
Externally heated engine
Valve engine
Stirling engine

ABSTRACT

A two-stroke, externally heated valve engine (EHVE) with a heater, a cooler and two blowers is simulated. The engine is entirely different from a typical Stirling engine. The pressure ratio p_{max}/p_{min} of its cycle is higher, but the engine volume and the mean value of the heat exchanger wall temperatures are the same. The power and efficiency of the EHVE and Stirling engines under the same maximum pressures are compared. The results show that the EHVE engine reaches almost the same level of performance as the Stirling engine, while using only available atmospheric air, rather than helium.

1. Introduction

In this paper, a new type of externally heated valve engine (EHVE), fully described in [1], is examined and quantitative results of its performance are presented. Schematic views of the engine are shown in Figs. 1 and 2.

Stirling engines are well known externally heated devices and remain a subject of current research [2–6]. Such engines have similarities to the EHVE, including: external heating; high thermal efficiency; multi-fuel capability; low noise generation; and low pollution when a combustion process is used as the heat source. A general feature of the EHVE and Stirling engines is the ability to use a range of heat sources. When a combustion process is used for this purpose, the burning arrangement may be optimised for a particular fuel. However, heat sources are not limited to combustion processes only, but can involve any type of energy capable of reaching the required temperature.

There are many papers showing experimental results of different Stirling (or similar externally heated) engines designed to use various alternative sources of energy, see [7–24], although not all were intended to reach high performance levels. Applications range from demonstration devices such as [23], through general purpose machines [7,21], solar heated [13], marine use [17,26], to potential outer space energy conversion [25]. The reader can find a comprehensive review of such solutions in [26–29] and a summary of the performance of a number of existing machines in [4].

Numerical simulations of the EHVE operation are compared with the experimental results presented for the Stirling engine described in [2,3] (1987–1988). The engine has a compact mechanical form and comparatively high power and efficiency at a total volume of 588 cm^3 enclosed in four double-action cylinders with four piston rods. The working gas is helium. Later Stirling engines described in [4–6] (2001–2003) have analogous or even lower effectiveness at similar design parameters. An initial comparison of the EHVE and an example of the Stirling engine has been made already in [30], but taking into account the later results developed in [31], such evaluation could be too optimistic for the EHVE. That evaluation is expanded and completed here.

2. Design aspects of the EHVE

The EHVE in the earlier form as shown in [30] exists as a prototype version ([31], Fig. 3). The experimental results have already proven the concept. In the prototype, an electric heating device was applied. However, independently of its type, it resulted in insufficient heat being delivered during the period when the engine valves were closed. An intensive flow of air is required in the heater throughout the complete cycle. Therefore, two centrifugal blowers B_1 and B_2 were added to the model of the EHVE in order to improve the heat exchange rate. Their power requirements are minimal but raise the heat exchange level when the engine valves are closed. The version of the EHVE discussed here is equipped with a single heater and a single cooler. The volumes

* Corresponding author.
E-mail addresses: Zbyszko.Kazimierski@p.lodz.pl (Z. Kazimierski), Jerzy.Wojewoda@p.lodz.pl, j.wojewoda@abdn.ac.uk (J. Wojewoda).

http://dx.doi.org/10.1016/j.enconman.2013.12.055
0196-8904/

Nomenclature

A	surface area (m^2)
D, d	diameters (m)
h_{SBi}	enthalpy isentropic increase of blowers (J/kg)
L	mechanical work (J)
l	length of tubes (m)
$\dot{m}_j$	mass flow rate (kg/s)
p	pressure (N/m^2, bar)
P	power (W, kW)
n	number of tubes
Q	heat (J)
$\dot{Q}_A$	heat flow in the surface area (W)
R	specific gas constant (J/kg K)
Re	Reynolds number
S	entropy (J/kg K)
T	temperature (K)
V	volume (m^3)
α	crankshaft angle (rad, °)
$\alpha_{j,k}$	angle of valves (rad)
η	efficiency
κ	isentropic expansion index
ω	angular velocity of the crankshaft (rad/s)
Subscripts B_1, B_2	blowers
C	compressor
Cl	cooler
Cl_2, Cl_4	collectors of the cooler
E	expander
f	friction
H	heater
H_1, H_3	collector of the heater
i	number of the blowers (=1, 2)
j	number of the valve (=1, 2, 3, 4)
k	opening (k = 0), closing (k = c)
max	maximum
PH	pre-heater
w	wall

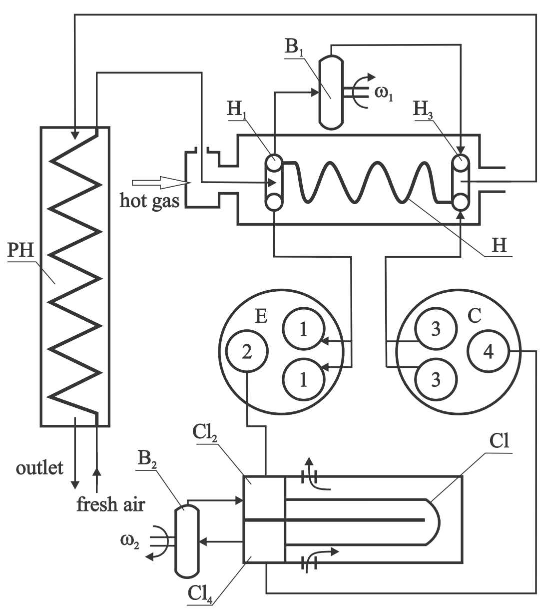

Fig. 1. Scheme of the transversal cross-section of the engine E – expander, C – compressor, H – heater, Cl – cooler, B_1, B_2 – blowers, 1, 2, 3, 4 – valves, H_1, H_3 – heater collectors, Cl_2, Cl_4 – cooler collectors, PH – pre-heater.

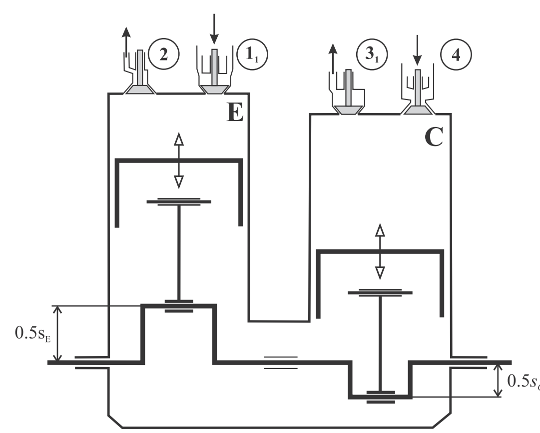

Fig. 2. Scheme of the longitudinal cross-section of the engine.

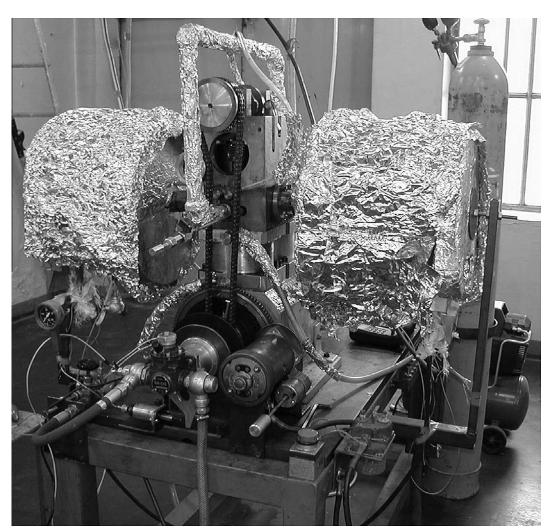

Fig. 3. General view of the EHVE prototype. Engine block in the middle, heat exchangers at sides – two electric heaters have been used in the experiments performed in 2001, see [4].

of each heat exchanger in the EHVE are at least 3–5 times larger than the volumes of the cylinders. The inlet and outlet collectors of the heater and the cooler are shown in Fig. 1. Their volumes may play a role of settling chambers for the working gas flow (equalizing pressure and temperature values in the exchangers in time).

An important advantage of this configuration is use of the most easily available working gas–atmospheric air. Also, it is possible to utilise any source of heat able to deliver an appropriate temperature to the heater, that is, from solar energy, through combustion of other media, to nuclear power. This makes the EHVE a suitable solution when available resources of oil and gas run out. The high temperature of the heating gas leaving the EHVE allows for the installation of an additional heat exchanger, a pre-heater (PH), improving thus efficiency, see Fig. 1 and Section 3. The earlier EHVE scheme, shown in [1], did not include such a device.