Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 61 (2014) 2395 – 2398

Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Thermal Analysis of Stirling Engine to Power Automotive Alternator Using Heat from Exhaust Gases

S. Alfarawi[a], M. Webb-Martin[b], S. Mahmoud[a], R.K. AL-Dadah[a*]

[a]School of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham, United Kingdom. B15 2TT
[b]BAE Systems, United Kingdom

Abstract

This paper investigates the development of small scale beta type Stirling engine to recover the exhaust heat from the main engine and to drive the alternator (decouple it from the main engine), thus providing the required electrical power for onboard devices. The ideal adiabatic model was used to predict the thermodynamic performance of the engine. CFD investigation was also carried out to optimise the heater and the cooler geometry of the Stirling engine. The results showed that it is possible to generate a power output of 1.5-2kWe at an ideal thermal efficiency of 40% and engine overall weight of 11-14kg.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: *Stirling Engine; Power Automotive; Exhaust Gases.*

1. Introduction

Passenger cars are increasingly equipped with more electrical and electronic devices like: air-conditioning system, electric power steering, electrical windows, built-in satellite navigation and infotainment consoles. These devices are usually powered by the car's battery, which is continuously charged by the alternator, taking power directly from the petrol or diesel engine's drive shaft whilst it is running. This reduces the amount of power available for propulsion, which in turn means that higher engine speed or greater throttle are necessary to achieve the desired acceleration in any given circumstance. This causes the car to use more fuel than it would otherwise burn which means more CO_2 is released into the atmosphere. Greater fuel consumption also reduces a car's maximum range. It follows that if the alternator is to be decoupled from the engine, a car could achieve a higher mpg, produce less CO_2 and travel further on a tank of fuel. The Stirling engine is an external combustion engine, so there is no fuel or gas exchanged between the inside and outside of the engine. This allows the engines to provide

* Corresponding author: Tel.:+44 (o) 1214143513
E-mail: r.k.al-dadah@bham.ac.uk

1876-6102 © 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.013

power from practically any source of heat, quietly and with little maintenance [1-5]. This work investigates the development of small scale Stirling engine that could provide the required electrical power for a modern passenger car (via recharging the battery) using the heat that is otherwise wasted through the exhaust.

2. Stirling Engine Modelling

Fig 1 outlines the ideal adiabatic model used to predict the thermodynamic performance of the engine configured with five components including compression volume, cooler, heater, regenerator and expansion volume. The gas in the cooler and heater is maintained at isothermal condition at temperatures T_k and T_h, respectively. Both the regenerator matrix and gas in the regenerator volume have linear temperature distribution: the gas flowing through regenerator–cooler interface being at cooler temperature T_k, regenerator–heater interface at heater temperature T_h.

The governing equations for the adiabatic model are derived by applying the energy equation and the equation of state to each of the five engine components as shown in equations 1 and 2:

$$dQ + c_p\,Tdm = dW + c_v\,Tdm \quad (1)$$

$$dp/p + dV/V = dm/m + dT/T \quad (2)$$

Q and W are heat and work transfer respectively, T is temperature, p is pressure, V is volume, m is mass, c_p and c_v are the specific heat capacity for constant pressure and constant volume respectively. The resulting ordinary differential equations were solved simultaneously using stepwise fourth order Runge-Kutta integration over the complete cycle. In order to achieve a power output of around 2kW, the following parameters were used: hot end temperature of 850 K, the cold end temperature of 450K, mean pressure of 2MPa, rotational speed of 715 rpm, regenerator volume of 541cc, compression swept volume of 611cc and expansion swept volume of 814cc. Fig 2 shows the PV diagram, compression and expansion temperatures versus the crank angle. Fig 3 shows the variation of the energy transfer rate to or from the various components of the Stirling engine with the crank angle and table 1 shows the total rate of energy Results from this model show that a power output of 2.1kWe at ideal thermal efficiency of 40% can be achieved with engine overall weight of 14kg.

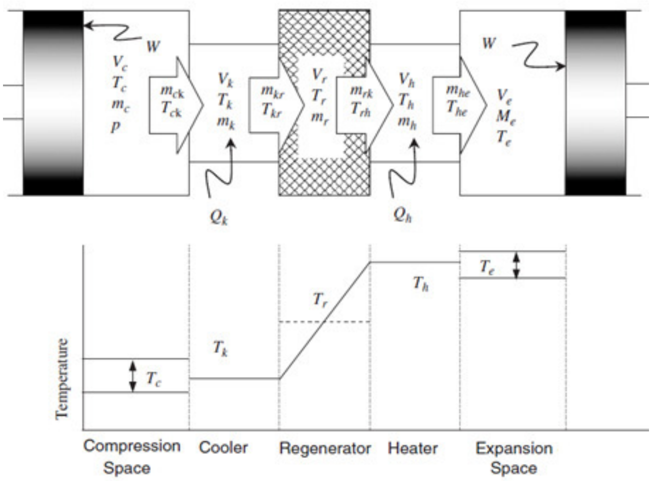


Fig.1. Ideal adiabatic model.

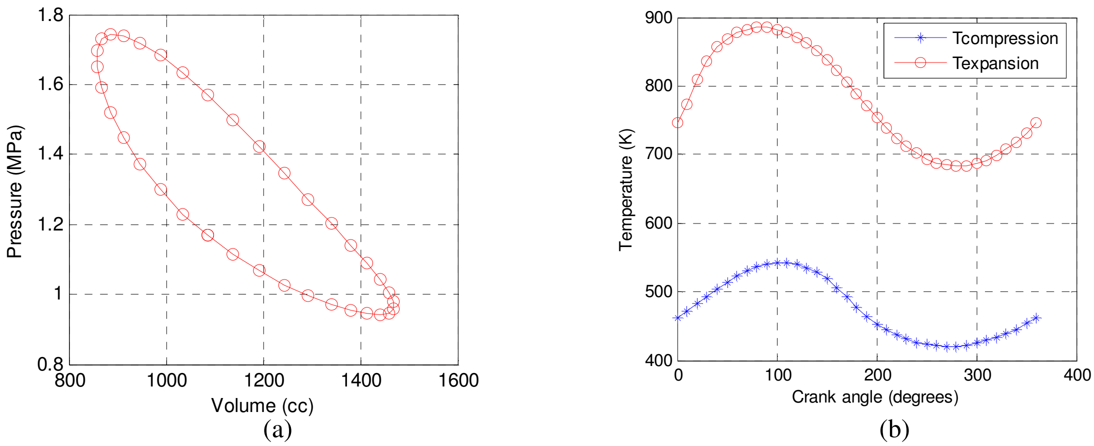


Fig. 2. (a) PV diagram and (b) Compression and expansion temperatures versus crank angle.

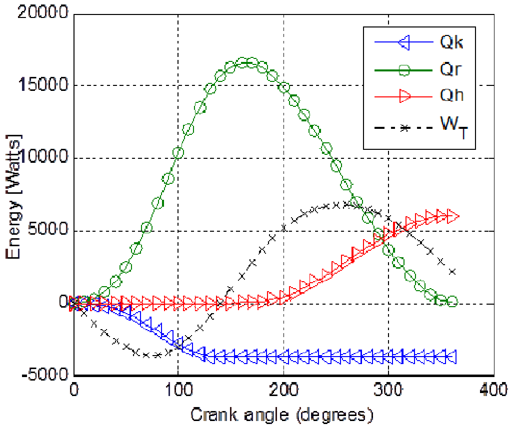


Fig. 3. Rate of energy transfer versus crank angle.

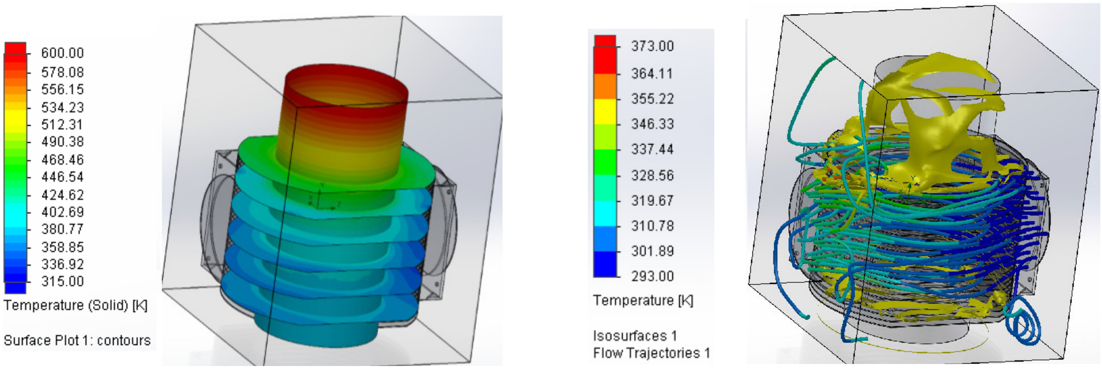
Table 1. Rate of energy transfer

Parameter	Value
Total mass of the gas	13.18[g]
Heat transferred to the cooler Q_k	-3204.43[W]
Net heat transferred to the regenerator Q_r	0
Heat transferred to the heater Q_h	5355.93[W]
Total power output W_T	2152.68[W]
Thermal efficiency	40.2[%]

Also an iterative study was carried out using Solid Works Flow Simulation to optimize the geometry of the cooler and the heater. Results showed the effectiveness of using cooling fans to reduce the cooler temperature from an average of 457K (Fig 4(a)) to an average of 333K (Fig 4(b)). Also results showed that more uniform temperature distribution on the heater side can be achieved by modifying the heater chamber size and the angle of deflection as shown in Fig 5.

3. Conclusions

Modern passenger cars are increasingly requiring more electrical power for auxiliary and user comfort equipment. Currently, such electrical power is provided by the battery which is charged by the alternator driven directly from the main engine. This leads to increasing the size of the main engine, the fuel consumption and CO_2 emissions. The concept of driving the alternator using Sterling engine powered the exhaust products from the main engine offers the potential of improving the overall efficiency and reduce CO_2 emissions. This work combined the use of adiabatic thermodynamic modelling and CFD to investigate the feasibility of such concept. Results showed that it is possible to generate a power output of 1.5-2kWe at ideal thermal efficiency of 40% and the engine overall weight of 11-14kg.



(a) (b)

Fig. 4. Effect of using cooling fan on cooler temperature distribution.

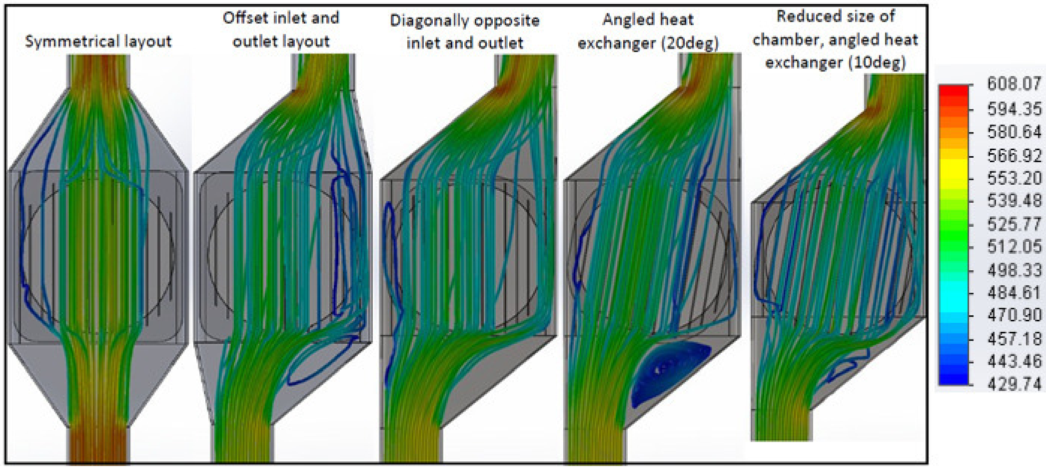


Fig. 5. Effect of heater chamber size and flow direction

References

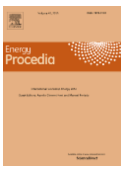
[1] Reader GT, Hooper C. Stirling engines .*University Press*, Cambridge; 1983.

[2] Thombare DG, Verma SK. Technological development in the Stirling cycle engines. *Ren and Sust En Revs* 2008; **12:**1–38.

[3] Kongtragool B, Wongwises S. Investigation on power output of the gamma-configuration low temperature differential Stirling engines. *Ren En* 2005*;* **30:**465–476.

[4] Cinar C, Yucesu S, Topgul T, Okur M. Beta-type Stirling engine operating at atmospheric pressure. *Int. J Applied Energy* 2005; **81**:351–357.

[5] Ehsan M, Shah M Z, Hasan M, Hasan SMR. Study of Temperature Profile in Au-tomotive Exhaust Systems for Retrofitting Catalytic Converters. *International Conference on Mechanical Engineering* 2005; Dhaka, Bangladesh.



Biography

Mr. S. Alfarawi is a Ph.D student at University of Birmingham. He graduated from Mechanical Engineering Department at University of Benghazi in Libya. He was a teaching assistant in this University and then was awarded a Master degree in Mechanical Engineering. He worked as a staff member since 2007.