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Advanced Materials Research
ISSN: 1662-8985, Vols. 712-715, pp 1625-1629
doi:10.4028/www.scientific.net/AMR.712-715.1625
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Online: 2013-06-27

Thermodynamic Performance Analysis of Stirling Engine with a Nodal Analysis Method

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Keywords: Stirling engine; nodal analysis method; calculation error

Abstract: A nodal analysis method for thermodynamic analysis of Stirling engine is modified based on the check of mechanical loss and the temperature of the heater and cooler. A computational modeling for simulating the process of oscillating flow and heat transfer occurring in the P-40 four-cylinder double-acting Stirling engine has been developed, and the changing effects of different parameters such as the internal pressure, temperature, velocity, power and efficiency are obtained. Numerical simulation results show that they coincide with the testing data given by NASA. The influence of speed, working fluid and average pressure on the engine output performance is analyzed by the modified nodal analysis method. This method is a useful tool for the optimal design and operating characteristic analysis of Stirling engine.

Introduction

As a closed-loop regenerative engine, Stirling engine is a reciprocating power machine in addition to steam engine and internal combustion engine. It has many advantages like using various kinds of energy, high efficiency, less exhaust pollution, low noise, low reliable operation and maintenance cost. Stirling engine is therefore a kind of power device to alleviate the energy shortage and environmental pollution problems [1]. Stirling engine also has been used in different areas such as solar energy, waste heat recovery, and etc.

The simulation of Stirling engine is difficult because there is unsteady oscillating flow of compressible working fluid inside the engine. Presently, we can only make simplified assumptions of the internal flow, and get the simplified analysis method for Stirling engine. Schmidt's isothermal analysis [2,3] and Urieli's adiabatic analysis [4] are the classical method for the preliminary analysis and design of Stirling engine. But due to many assumptions, the preliminary analyses fail to present the actual performance of Stirling engine. Based on the thoughts of adiabatic analysis, Iskander Tlili divided the regenerator into two parts, and established the model which had taken the loss into consideration [5]. So far there is little research about the calculation error and disadvantages of the nodal analysis method at home and abroad.

Based on the check of mechanical loss and the heat exchanger temperature, this paper has established the governing equations for thermodynamic model, and simulated the working condition and off-design points of Stirling engine. The analysis method is verified by the testing data for the P-40 four-cylinder double-acting Stirling engine, and provides an effective way to analyse the thermal cycle of Stirling engine.

Mathematical Model

The closed-loop system of Stirling engine is composed of the compression chamber, cooler, regenerator, heater and expansion chamber. In the basic equation for the working process simulation, the following assumptions are made:
(1) one-dimensional quasi-steady flow;