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Startup mechanism and power distribution of free piston Stirling engine

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ABSTRACT

The startup mechanism and power distribution of free piston Stirling engine (FPSE) are different from the traditional crank connecting Stirling engine. All the time, there is no paper to study the startup mechanism and power distribution of FPSE. In this paper, three necessary conditions of startup of FPSE have been first proposed. Theoretical analysis and numerical simulation have been used to illustrate the α, β and γ types FPSEs whether meet the startup conditions. Related experiments have been done to prove the theoretical analysis and numerical simulation on an α and a β type FPSEs. According to the theoretical analysis, numerical simulation and experiments, some important results have been obtained. If a FPSE works stably, during a complete cycle, not only the total work in compression and expansion space should be positive, but also the work done by gas to both piston and displacer should be positive. To the α type FPSE, over a complete cycle the work done by gas to piston is negative and the work done by gas to displacer is positive. It does not meet the startup conditions. Therefore, the α type FPSE is impossible to startup. To the β and γ type FPSEs, over a complete cycle the work done by gas to displacer is positive. However, over a complete cycle the work done by gas to piston could be positive or negative. So it maybe meet the startup conditions of FPSE or not. So the β and γ type FPSEs could start up or not. Whether the β and γ type FPSEs could start up depends on the engine design and parameters configuration.

1. Introduction

The traditional crank connecting Stirling engines were invented in 1816 by Robert Stirling [1]. In general, the traditional crank connecting Stirling engines include α, β and γ types as shown in Fig. 1 [2]. The main design feature of traditional crank connecting Stirling engine is that the piston and the displacer are connected by the crank. Many researchers have studied the α, β and γ type traditional crank connecting Stirling engines [3–7]. It start easily and work stably.

The FPSE was invented by William Beale in 1964 [8]. In the FPSEs there is no constraint between the motions of power and displacer pistons. In other words, the pistons are free to move independently and the motions of the pistons are coupled through the pressure dynamics [9]. The FPSE works to drive a linear alternator, and because of its simple configuration, light weight, and maintenance free, long operating life, the FPSE has widely use prospect for producing electricity from solar energy or nuclear [10]. All the time, people think that the FPSEs also include α, β and γ types as shown in Fig. 2.

The studies about FPSEs mostly focus on the thermodynamics and dynamic. To predict the performances of FPSEs, both accurate thermodynamic and dynamic model are required [11]. Many papers have analyzed and optimized the Stirling engine from the thermodynamic model [12–16]. In these papers, different thermodynamic models are used to analyze the affections of the main parameters to output power and efficiency. Through these analyses many useful results have been found. The effectiveness of heater, regenerator and cooler are key to the efficiency of FPSE. The displacements phase angle of piston to displacer is the essential condition for a FPSE to start up successfully. When the heat losses have been taken into account, there is an optimized absorber temperature to a Stirling engine. MT Mabrouk [17] proposes an unsteady analytical model to calculate the gas leakage mass flow rate by considering an oscillating flow in the annular clearance and

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Nomenclature

A_p	sectional area of piston, mm^2
A_d	sectional area of displacer, mm^2
A_r	sectional area of displacer rod, mm^2
P	pressure of work space, MPa
R	the ideal gas constant
W	the cycle work of total space
W_e	the cycle work of expansion space
W_c	the cycle work of compression space
W_{g-p}	work done by gas to piston
W_{g-d}	work done by gas to displacer
V_c	volume of compression space, mm^3
V_e	volume of expansion space, mm^3
V_{eo}	volume of expansion space when both the piston and displacer at the equilibrium position, mm^3
V_{co}	volume of compression space when both the piston and displacer at the equilibrium position, mm^3
V	charge volume of cell
T	gas temperature in the cell
T_{in}	gas temperature into the cell
T_{out}	gas temperature out the cell
Q	power into the cell
Q_e	power into the expansion space
Q_c	power into the compression space
x_d	displacement of displacer, mm
x_p	displacement of piston, mm
$\dot{m}_{in}$	mass flow into the cell
$\dot{m}_{out}$	mass flow out of the cell
c_p	specific heat at constant pressure
c_v	specific heat at constant volume

Superscripts

α	alpha-type FPSE
β	beta-type FPSE
γ	gamma-type FPSE

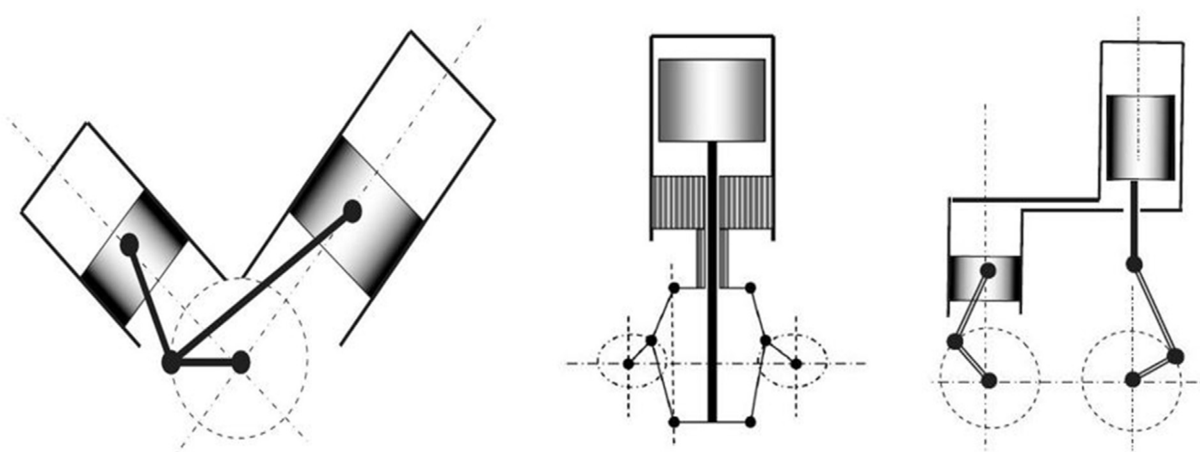

Fig. 1. The α, β and γ type traditional crank connecting Stirling engines.

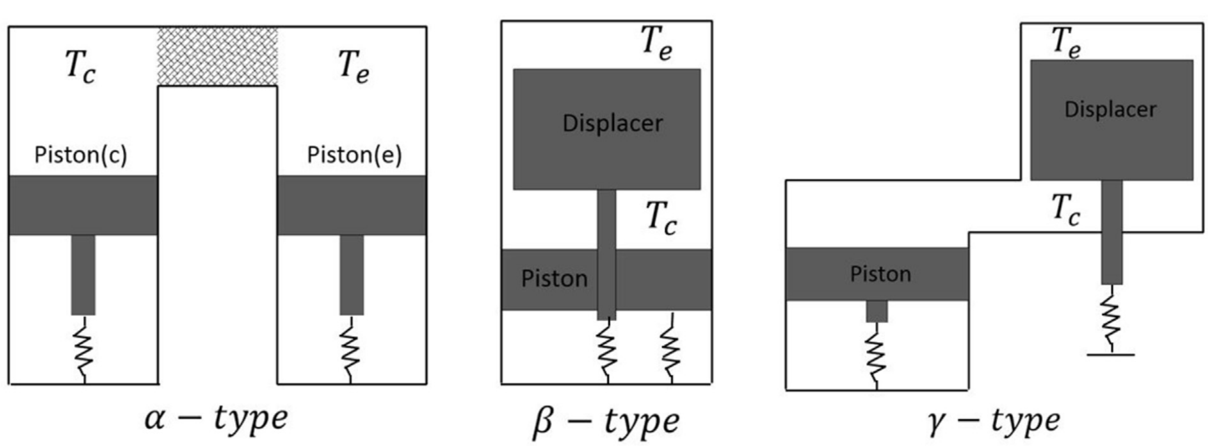

Fig. 2. The α, β and γ type FPSEs.

to evaluate the power lost. In paper [18] the thermal and mechanical losses have been considered in the model to optimize the engine. It was found that the performances of the engine are more sensitive to its regenerator efficiency. In paper [19] a new