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Research paper

Effects of pocket shape and ignition slot locations on the combustion processes of a rotary engine fueled with natural gas

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HIGHLIGHTS

- A three-dimensional simulation model based on the chemical reaction kinetics was established.
- The pocket shape of rotor and the position of a new-designed ignition slot is optimized.
- The tumble and the high speed oblique flow near the TSP is beneficial for combustion rate.
- The optimal scheme is a middling pocket with an ignition slot located at the middle of rotor surface.

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ABSTRACT

This work aims to numerically study the performance, combustion and emission characteristics of a side-ported natural-gas-fueled rotary engine under different pocket shapes and ignition slot positions. Simulations were performed using multi-dimensional software FLUENT 14.0. On the basis of the software, a three-dimensional dynamic simulation model was established by writing dynamic mesh programs and choosing a detailed reaction mechanism. The three-dimensional dynamic simulation model, based on the chemical reaction kinetics, was also validated by the experimental data. Simulation results showed that a bigger intensity of the tumble, a larger area of the high speed oblique flow and a higher average flow speed in the middle of the combustion chamber can make the flame propagation speed increase. When the combustion chamber configuration had a middling pocket coupled with an ignition slot located at the middle of the width direction of rotor surface, the combustion rate is the highest. As a result, the cylinder pressure and the intermediate OH increased significantly. Compared with the combustion chamber configuration, which had a flat-top pocket without ignition slot, it showed a 10 percent increase in the peak pressures, but a certain increase in NO emissions.

1. Introduction

The side-ported rotary engine not only inherits the advantages of the peripheral-ported rotary engine, such as large specific power output, simple and compact design, multi-fuel capability and low noise, but also is more likely to be a potential alternative to the reciprocating engine in terms of its favorable performance at low speeds [1]. Acting as an ecologically sensitive and efficient fuel, natural gas is often recognized as a promising option put forward by governments for a sustainable energy system [2,3]. The side-ported natural gas-fueled rotary engine can bring the advantages of the side-ported rotary engine and natural gas together in a highly effective way. So, it is imperative to study the combustion mechanism of the side-ported natural gas-fueled rotary engine. How to improve the efficiency of the rotary engine has been a recurring question in engine research. This is chiefly due to higher unburned hydrocarbon emissions resulting from the flattened combustion chamber of the traditional rotary engine [4]. When natural gas is used in the rotary engine, its low burning speed could also exacerbate the above problem. Since the 1980s, several studies have attempted to improve the fuel efficiency and exhaust emissions of the rotary engine [5–8]. In recent years, a lot of work has been done to increase the efficiency of the rotary engine. Some new technical methods have been applied to the rotary engine. For example, new apex seals were designed for the rotary engine to improve sealing [9,10]. Direct-injection and

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turbocharged systems also were used to improve the efficiency of engines [11,12]. Amrouche et al. added hydrogen to gasoline to improve the thermal efficiency and power output [13]. However, previous studies suggest that the combustion chamber configuration still plays a critical role both in the flow field and the combustion process in the cylinder. For example, DeFilippis et al. [14] used laser doppler velocimetry (LDV) to study the effect of combustion chamber shape on the flow field of a peripheral-ported rotary engine. Reflection type Schlieren method was used by Hasegawa and Yamaguchi [15] to study the effect of combustion chamber shape on the flow field in the rotor housing central plane of a side-ported rotary engine. Abraham et al. [16,17] measured the indicator diagrams under different working conditions and studied the effect of combustion chamber shape on the combustion process through numerical simulation. Despite these works, in terms of experimental research, due to the limitations of the experimental setups, only the flow field at low-speed testing conditions could be directly measured. That is, the combustion process under normal engine operating conditions (2000 rpm or above) could not be tested. In terms of numerical simulations, although the mathematical models have been greatly improved over the past two decades, the three dimensional investigation coupled with a reasonable turbulence model, combustion model and CHEMKIN mechanism is still rare. Besides the combustion chamber shape, ignition slot is another key that plays a complementary role in the combustion process. Because it can change the flow field around the spark plug and thus bring changes to the combustion process. In this study, through writing dynamic mesh programs, choosing the RNG $k-\varepsilon$ turbulent model, the eddy-dissipation concept (EDC) combustion model and a detailed reaction mechanism on the basis of the FLUENT simulation software, a three-dimensional dynamic simulation model based on the chemical reaction kinetics was established. The three-dimensional dynamic simulation model was validated by comparing it with the experimental results. Some important information difficult to obtain through experiments was reflected, including the flow field, the temperature field and the concentration fields of some intermediate species. Furthermore, the effect of the pocket shape and the position of ignition slot on the combustion process is simulated and analyzed. The study provides a theoretical foundation to improve and optimize the design of a rotary engine, like mixture formation and stratified combustion etc.

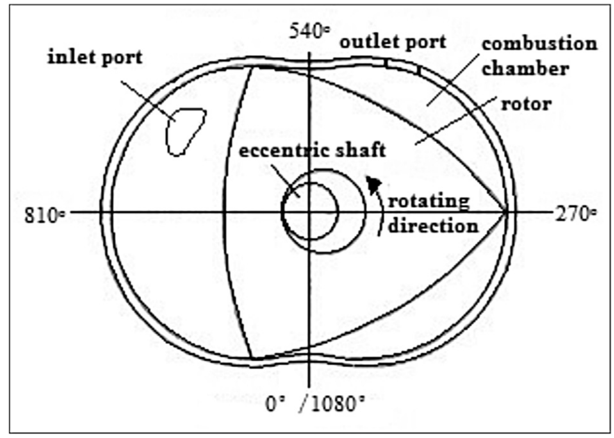

Fig. 1. Schematic of side-ported rotary engine.

Table 1
Engine technical specifications.

Engine parameters	Value
Number of rotors	Single rotor
Cooling	Air cooled
Ignition source	Spark plug
Displacement	160 cm^3
Compression ratio	8–1
Generating radius	69 mm
Eccentricity	11 mm
Chamber width	40 mm
Number of rotor	1
Intake timing	Advance angle 70°CA(ATDC), delay angle 63°CA(ABDC)
Exhaust timing	Advance angle 62°CA(BBDC), delay angle 70.5°CA(ATDC)

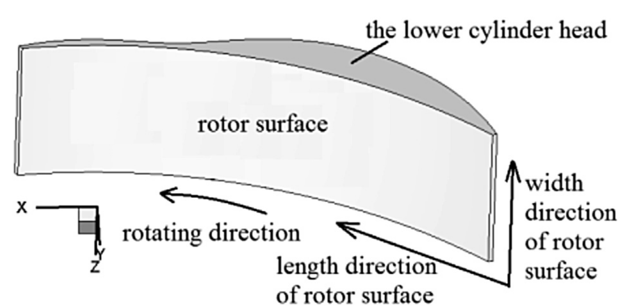

Fig. 2. Schematic of the definition of direction on rotor surface.

2. Geometric model generation and meshing

2.1. Computational domain

In the present study, a premixed-charge side-ported natural-gas-fueled rotary engine was chosen as the research object. All computations were made with equivalence ratio of 0.8. A schematic diagram of the test engine is shown in Fig. 1. Technical specifications of the engine are listed in Table 1.

For the convenience of discussion, few technical terms will be defined in this section. The direction of rotor surface is defined in Fig. 2. Fig. 3 shows the schematic of four different pocket shapes. These parameters are defined in Table 2. All pockets of four combustion chambers without ignition slots are located in the front of the length direction of rotor surface and the middle of the width direction of rotor surface.

Fig. 4 shows the schematic of three different ignition slot positions. All three ignition slots were opened on the base of case C. They are all located at the rear of the middling pocket. However, along the width direction of rotor surface, they are all located at different positions. These parameters are defined in Table 3.

2.2. Geometric model generation and meshing

Since the three combustion chambers are symmetrically structured in the rotary engine, only one combustion chamber is simulated. Considering the operational characteristics of a rotary engine, the intake and exhaust channels are set to have a static mesh since there are no moving parts, and the combustion chamber is modeled with a dynamic mesh due to the movement of the rotor. For the dynamic mesh, unstructured triangular grids were adopted. The grid size is set to 2.2 mm through the grid independence check, and the geometry and the mesh of the rotary engine are shown in Fig. 5.

For dynamic mesh generation, DEFINE_CG_MOTION is used to specify the motion of a particular dynamic zone in ANSYS Fluent by