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ORIGINAL ARTICLE

Three-dimensional simulation of a novel rotary-piston engine in the motoring mode

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Abstract In this simulation study, the flow and thermal characteristics of a novel rotary-piston engine, which is a kind of internal combustion engines, were investigated by computational fluid dynamics and the finite volume method. The structure of this engine is different to others, mainly for having 24 cylinders during the motoring mode. As a novel engine, creation of numerical models based on Reynolds average Navier Stokes (RANS) simulation and analysis of various speed engines on the flow and thermal fields during intake and compression strokes are the focus of this work. The results were illustrated in term of the streamline patterns, in-cylinder temperature and pressure profile, swirl ratio (SR), wall heat flux, and turbulent velocity fluctuation. The present study indicates that, the mean pressure, temperature trace, and heat loss from the wall increase when switching to a higher engine speed. The temperature distribution reveals that the maximum temperature is restricted in the center of the combustion chamber near top dead center (TDC). Also, the maximum amount of turbulent velocity and swirl ratio are achieved at the beginning of the intake stroke and near TDC. It is observed that the obtained numerical results are in general agreement with the available experimental data.

1. Introduction

The rotary-piston engine is very efficient in comparison to the conventional internal combustion engines. The rotor is driven by 24 combustion events in each revolution. Since

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Nomenclature

CFD	computational fluid dynamics
rpm	revolutions per minute
TDC	top dead center
aTDC	after top dead center
bTDC	before top dead center (unit: kg)
UDF	user defined function
V_p	mean rotor speed (unit: m/s)
V	flow velocity (unit: m/s)
k	turbulent kinetic energy (unit: m^2/s^2)
n	engine speed (unit: rpm)
SR	swirl ratio
u	radial velocity (unit: m/s)
v	tangential velocity (unit: m/s)
u'	velocity fluctuation (unit: m/s)
h	cam height (unit: mm)

Greek letters

ρ	density (unit: kg/m^3)
θ	rotor angle (unit: °)
$\forall$	cell volume (unit: m^3)
ε	dissipation rate of turbulence (unit: m^2/s^3)

the upper and lower faces of the cam and rotor are 180 degrees out of phase, the engine is always balanced and exhibits minimal vibration.

There are numerous defining characteristics that distinguish a rotary-piston engine from a usual conventional reciprocating engine. The rotary-piston engine has far fewer moving parts, including the rotor and the 12 vanes. On the other hand, a similar four-stroke piston engine has at least 40 moving parts, as well as pistons, connecting rods, camshaft, valves, valve springs, rockers, timing belt, timing gears and crankshaft.

The rotor and integral shaft in the rotary-piston engine spin constantly in one direction, instead of violently changing directions like the pistons in a conventional reciprocating engine do. The rotary-piston engine is entirely balanced with Combustion chambers on opposite sides of the rotor positioned to annihilate vibrations completely.

The power transmission system in a rotary-piston engine is also smoother. Each combustion event lasts through 30° of the rotor's revolution; therefore, 24 combustion events power each revolution of the rotor. This means that the rotary-piston engine delivers continuous power during each rotation of the output shaft.

Each chamber performs the “Otto” engine four-cycle process: intake, compression, power and exhaust. For each rotation of the rotor, the volumes of the 24 chambers alternatively expand and contract to draw air into the rotary-piston engine, compress the air, inject fuel at the defined moment to make optimum power as the gases expand, and then expel the exhaust.

The intake phase begins when each chamber moves through the intake port. As the intake port is exposed to the chamber, the volume of that chamber is nearing its minimum. When the rotor moves past the intake port, the volume of the chamber expands, drawing air into the chamber. By the time the chamber passes the intake port, that chamber is sealed off and compression starts.

When the rotor continues its motion around the housing, the volume of the chamber gets smaller and the air gets compressed. Once the chamber is exposed to the injector, the volume of the chamber is again nearing its minimum and spontaneous combustion begins.

The pressure of combustion forces the rotor to turn as the chamber volume increases. The combustion chamber continues to expand, moving the rotor and creating power. At the moment the peak of the chamber passes the exhaust port, the high-pressure combustion gases expel the exhaust port. As the rotor continues to move, the chamber begins to contract, forcing the remaining gasses out of the exhaust port. Once the volume of the chamber is close to its minimum, the peak of the chamber passes the intake port and the whole cycle begins again.

According to aforementioned literature review, almost all numerical and experimental studies on performance have focused on typical internal combustion engines. It is important to note that despite the RadMax Technologies constructed this rotary piston engine [1], the numerical simulation of this engine has never been accomplished yet. In this study, the flow and thermal characteristics of novel rotary engines are numerically investigated by considering the RANS turbulence model. In fact, the temperature distribution, swirl ratio and the flow pattern inside the combustion chamber are the key parameters for the combustion simulation [2]. Therefore, the research focuses on analyzing the cold flow characteristics and the factors that are important for combustion process.

The motoring mode of the conventional internal combustion engines had been investigated numerically in numerous studies [3–7]. In numerical studies characteristics of the flow motion were investigated in cylinder and piston bowl during intake and compression strokes.

Mao et al. [8] calculated the complete simulation of both intake and compression strokes in an axisymmetric engine. They showed the influence of different turbulence models and the numerical precision of the simulations. However, the numerical simulation results were not validated with experimental results. Later, Aita et al. [9] investigated the effect of swirl motion inside the cylinder during a complete intake and compression stroke. They showed that a strong interaction was found between the swirling motion and the shape and position of the piston bowl. The obtained simulation results then were compared with experimental data.

Based on numerical studies of Chen et al. [10], a complete intake and compression stroke was performed

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