Three-dimensional Phenomenon of Continuously Rotating Detonation Engines

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Abstract: The effect of chamber depth on the continuously rotating detonation engines(RDE) flow field is discussed. The results demonstrate that the radial dimension is not obvious when the chamber depth is small. However when the chamber depth is 10mm or 14mm, the radial dimensional phenomenon is more and more obvious. At the head wall, shock waves reflect repeatedly between the inner wall and outer wall. Both regular reflection and mach reflection exist at the head wall. The length of mach stem increases as the chamber depth is increased.

Keywords: RDE, Numerical Simulation, Three-dimensional Phenomenon, Shock Wave Reflection.

1 Introduction

In recent years, the continuously rotating detonation engines (RDE) based on detonation combustion has been extensively studied [1]. The resolution of numerical simulation on RDE is higher and higher, so we obtained more accurate and perfect flow field results. But most of the numerical results were based on the two-dimensional chamber and ignored the depth along the radial direction[2]. However, the detailed three-dimensional structure of detonation has remained unclear because of its fast propagation speed and the difficulty of three-dimensional visualization by experimental measurement devices. The three-dimensional numerical simulation of RDE is very necessary for understanding the complex flow field structure of rotating detonations.

2 Physical Modeling and Numerical Method

The governing equations are the compressible and reactive three-dimensional Euler equations. A one-step chemical reaction model is used in this simulation. A detailed introduction of all the equations and parameters can be found in Ref.[3,4]. Flux terms are solved by using the five-order so-called monotonicity preserving weighted essentially non-oscillatory scheme (MPWENO), and the time integration is performed by using the third-order total variation diminishing (TVD) Runge-Kutta method.

The combustion chamber of the RDE is a coaxial cavity with a toroidal section. A detonation wave propagates azimuthally in the annulus while a combustible mixture is injected from the head-end, and then the burnt gas spurts out of the downstream exit. At the head-end, there are a large number of Laval micro-nozzles to axially inject premixed stoichiometric hydrogen/air gas into the combustion chamber.

3 Results and Discussion

We consider the effect of different chamber depth on the RDE flow field. The inner radius of the combustion chamber is 3cm, and the outer radius is 3.4cm, 4cm or 4.4cm respectively.

Figure 1 shows the pressure and temperature contour after the detonation propagates stably. When the chamber depth is $\Delta = 10\text{mm}$ and $\Delta = 14\text{mm}$, it is seen clearly that there is shock wave reflection repeatedly between the inner wall and the outer wall at the head wall. The form of shock wave reflection is not only limited to regular reflection, but also the mach reflection exists at the inner wall. The length of mach stem increases as the chamber depth is increased.

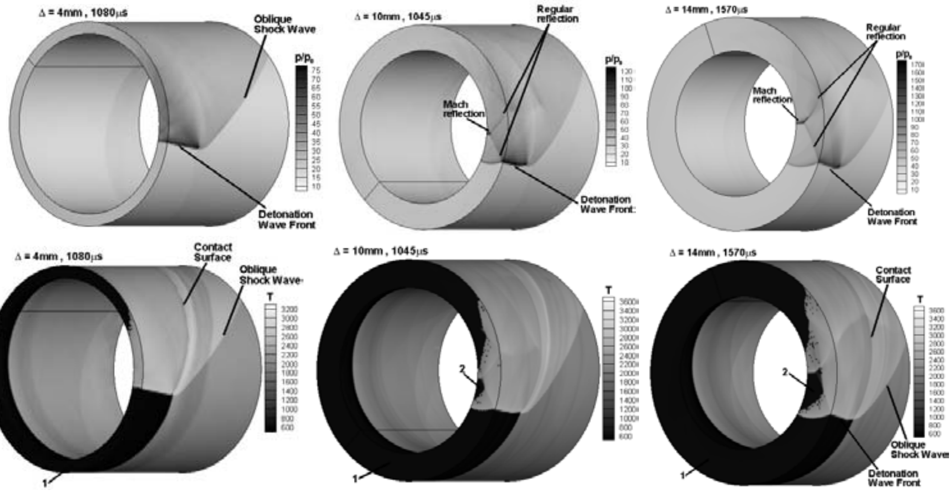

Figure 1: Pressure(up) and temperature(down) contour as the chamber depth is 4mm(left), 10mm(middle), and 14mm(right).

Figure 1 shows that the difference of flow field along the radial direction is not obvious when the chamber depth is small. The difference of flow field is more and more obvious when the chamber depth increases. Flow field shows total different wave characteristics on the inner annular and outer annular. There are two strong waves on the inner annulus, one is the detonation front, and the other exists because of the mach reflection. At the front of the mach stem the pressure decreases because of the mach reflection, so a little fresh gas can be injected into the combustion chamber (as shown domain 2 in figure 1), and then it is burned rapidly. The pressure and temperature increase at the mach stem, so the second wave is stronger than the detonation wave on the inner wall.

4 Conclusions

When the chamber depth is small, the difference of flow field along radial direction is not obvious. Therefore, we can use the two-dimensional annular surface as approximate calculation domain in order to reduce computational cost. When the chamber depth is $\Delta = 10\text{mm}$ and $\Delta = 14\text{mm}$, the three-dimensional phenomenon cannot be ignored. There is shock wave reflection repeatedly between the inner wall and the outer wall at the head wall. The form of shock wave reflection is not only limited to regular reflection, but also the mach reflection exists at the inner wall. The length of mach stem increases as the chamber depth is increased.

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