ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–9

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/he

Experimental research on ignition, quenching, reinitiation and the stabilization process in rotating detonation engine

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ARTICLE INFO

Article history:
Received 22 May 2018
Received in revised form
4 August 2018
Accepted 9 August 2018
Available online xxx

Keywords:
Rotating detonation engine
Reinitiation
Stabilization process
Experimental research

ABSTRACT

This paper presents an experimental research on ignition, quenching, reinitiation and the stabilization process in hydrogen-air rotating detonation engine with an array of injection holes. The stabilization process can be divided into six sections, including deflagration, deflagration to detonation transition (DDT) process, coexistence of detonation with deflagration, coexistence of strong & weak detonations, unstable to stable detonation transition and stable detonation. The phenomenon of single-double-single wave transition is found and analyzed for the first time in the experiment. During the transition, the initial strong detonation wave weakens until it disappears, and the weak detonation wave becomes stronger until it propagates steadily. The reinitiation phenomenon is related to the injection pressures of the propellant. Increasing the injection pressure helps to reinitiate, thus avoiding the occurrence of the quenching phenomenon.

Introduction

Based on nearly isochoric combustion process, the detonation engine, especially the Rotating Detonation Engine (RDE), inherently enjoys higher thermal efficiency and specific impulse. Taking advantage of self-compressing and rotating detonation wave (RDW), the RDE is capable to run with a simple and compact structure. It is expected to break the bottleneck encountered by conventional deflagrations-based propulsion devices. Voitsekhoviskii [1] first proposed the basic concept of RDE. Fig. 1 shows the wave structure of a RDW in RDE. Fresh propellants are fed into the co-axial annular combustor from the wall of inlet. The detonation wave generated by the coupling of a leading shock and a chemical reaction zone propagates circumferentially in this annular combustor, after which the contact discontinuity comes closely on behalf of the boundary between freshly detonated products and older burnt products. The combustion products are exhausted at high velocity along the combustor outlet.

In recent years, the RDE has been extensively studied both theoretically and numerically due to its bright future. Zhdan et al. [2] numerically performed two-dimensional unsteady modeling of rotating detonation in an annular chamber with a hydrogen–oxygen mixture. Anand et al. [3] observed low frequency instabilities linked to two distinctly different types of instabilities in rotating detonation. Hishida et al. [4] numerically studied the detailed flow field structure of the rotating detonation with a two-step chemical reaction model. Raman et al. [5] analyzed the hydrogen-air detonation waves with vibrational nonequilibrium. Tang et al. [6] carried out the

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https://doi.org/10.1016/j.ijhydene.2018.08.064
0360-3199/

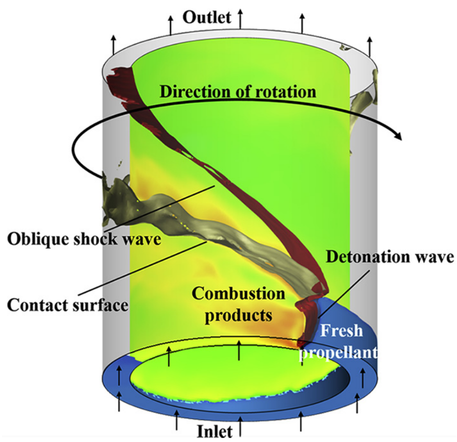

Fig. 1 – Wave structure of a RDW in RDE.

three-dimensional numerical investigations of the rotating detonation engine with a hollow combustor. Robert et al. [7] accomplished a LES study of deflagration to detonation mechanisms in a downsized spark ignition engine. Yao et al. [8] explored the phenomenon of the reinitiation of detonations in the RDE with a cylindrical combustion chamber. It was found that the detonation flow goes through three stages: initiation, quenching, and spontaneous reinitiation.

In the experimental investigation of RDE, different scales of RDE using gaseous fuels–oxygen mixtures or gaseous fuels-air mixtures have tested [9–17]. Fotia et al. [18,19] studied the propulsive performance and the ignition process of rotating detonation engines. Lu et al. [20] analyzed the experimental challenges, modeling, and engine concepts of rotating detonation wave propulsion. Experiments were carried out by Frolov et al. [21] on continuous-detonation combustion of ternary “hydrogen-liquid propane-air” mixture in a large-scale annular combustor. Grune et al. [22] presented an experimental investigation on detonation wave propagation in semi-confined layer geometries. Edyta et al. [23] showed for the first time in details that shock wave-boundary layer interactions are the key for an auto-ignition in the boundary layer in a smooth tube.

In previous studies, a great deal of research has been conducted on both single-wave and multi-wave phenomena [24–28]. However, there is little research on single-multiple-single waves. This paper presents an experimental research on ignition, quenching, reinitiation and the stabilization process in hydrogen-air rotating detonation engine with an array of injection holes. The stabilization process can be divided into six sections. The phenomenon of single-double-single wave transition is found and analyzed for the first time in the experiment. The reinitiation phenomenon is analyzed by changing the injection pressures of the propellant.

Experimental setup and methodology

Experimental system

Fig. 2 shows a schematic of the experimental system, including combustor, gas supply system, ignition system, data acquisition system and CMOS camera. Hydrogen and air are used as fuel and oxidizer.

The gas supply system is made up of source gas, gas supply lines, sonic nozzles and valves. Four gas cylinders are used for hydrogen and air. Each cylinder has the volume of 40 L and the initial pressure is 13.5 MPa. The sonic nozzles are used to measure the mass flow rate of hydrogen and air. The reducing valves are able to maintain a constant pressure at the valve exit. The check-valves prevent back flow. Gas feeding is controlled by a solenoid valve on each single pipeline. A computer program controls the solenoid valves and the spark plug separately.

The ignition system consists of a spark plug, an ignition loop and a pre-detonator. A pre-detonator connected to the combustor cylinder tangentially ignites the propellants in the main combustor. The pre-detonator is also filled with hydrogen and air, and the spark plug ignites the pre-mixed gas at the end. The pre-detonator includes a spiral for flame acceleration. Deflagration to detonation transition (DDT) is completed in the pre-detonator. The pre-detonator only needs to work at the beginning.

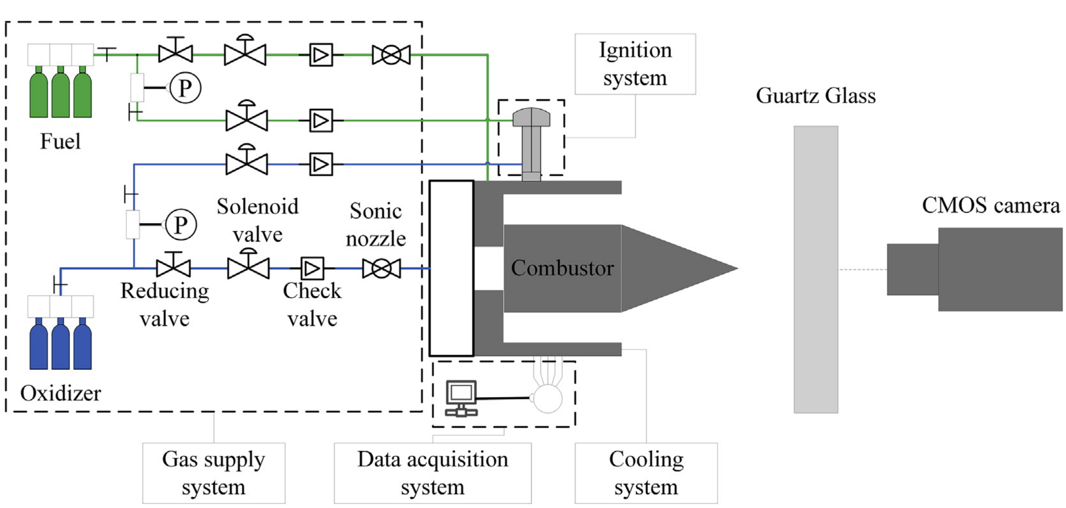

Fig. 2 – The experimental system.