Investigation for delay time of rotating detonation fueled by hydrocarbon-hydrogen mixture

Yepan Zhong [a], Yun Wu [a,b], Di Jin [a], Xin Chen [a], Xingkui Yang [a]

a Science and Technology on Plasma Dynamics Laboratory, Air Force Engineering University

Xi' an, 710038, China

b Institute of Aero-engine, School of Mechanical Engineering, Xi'an Jiaotong University

Xi'an, 710049, China

1 Introduction

As a combustion mode approximately to isochoric combustion, the detonation has been researched globally for its higher thermal efficiency than conventional isobaric combustion. Voitsekhoviskii firstly investigated the rotating detonation in the late 1950s [1] and the study related to the rotating detonation has been widely extended in recent years. Among the different detonation patterns, the rotating detonation has a high frequency (usually >1KHz), and the initiation of a rotating detonation wave (RDW) is only needed once. The continuous and self-sustaining propagating detonation wave ensure a huge application potential for the rotating detonation. Presently, the researches of the rotating detonation are mainly about the basic mechanism of the RDW itself and the performances evaluation of a rotating detonation engine (RDE). Annad et al. [2] has defined three basic modes of an RDW and Fotia et al. [3] studied the performances of an RDE with different nozzles. Also, the rotating detonation experiments with different fuels were conducted. Wolanski and Lin et al. [4-5] investigated the rotating detonation with CH4 and Frolov et al. [6] researched the rotating detonation with the hydrocarbon-hydrogen mixture. The process of the formation of an RDW is a complex process and it will influence the following propagation of the RDW. It was found that there existing a delay between the ignition time and the final formation of an RDW. Ma et al. [7] researched the effects of ignition energy on the initiation of an RDW and Wang et al. [8] demonstrated that the delay time of the initiation of an RDW is related to the pre-ignition time interval length.

To enhance the comprehension of the delay time in the initiation process of an RDW, the experiments with hydrocarbon-hydrogen mixture were conducted in this study.

Correspondence to: wuyun1223@126.com (Yun Wu)

2 Experimental Setup and Methodology

The experimental setup is shown in Fig 1, which consists of five parts namely a gas supply, combustor, ignition, controlling, and measuring system [9].

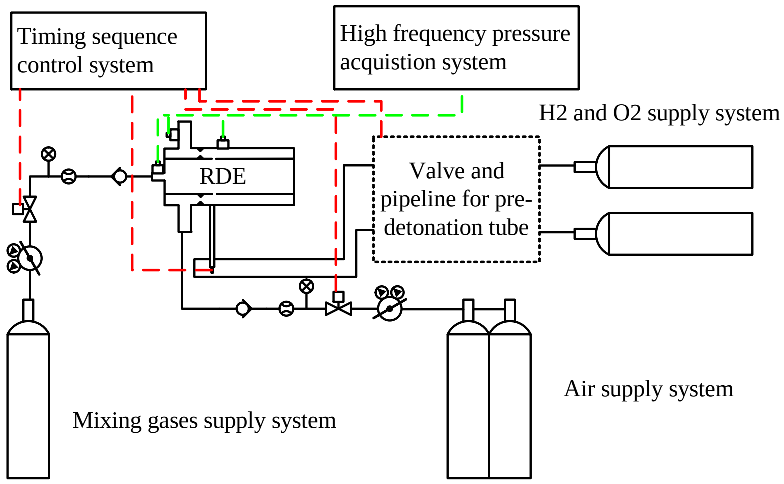

Fig 1 Sketch of the experimental system

The combustor used in the tests is an annular combustor with an outer diameter of 106 mm, inner diameter of 88 mm, and axial length of 80 mm. An orifice–slot injector is adopted, and the angle of the fuel and oxidizer injection is 60°. The ethylene-acetylene-hydrogen mixture is used as the fuel and air as the oxidizer. The components of the fuel are stored in a steel cylinder and homogenized in a specific ratio before being injected into the chamber. The flow rates of fuel and oxidizer are controlled by venturimeters and upstream pressure. A pre-detonator fueled by hydrogen-oxygen mixture is used to initiating the RDW. The gas feeding and ignition are controlled by the computer program and the time sequence is shown in Fig 2.

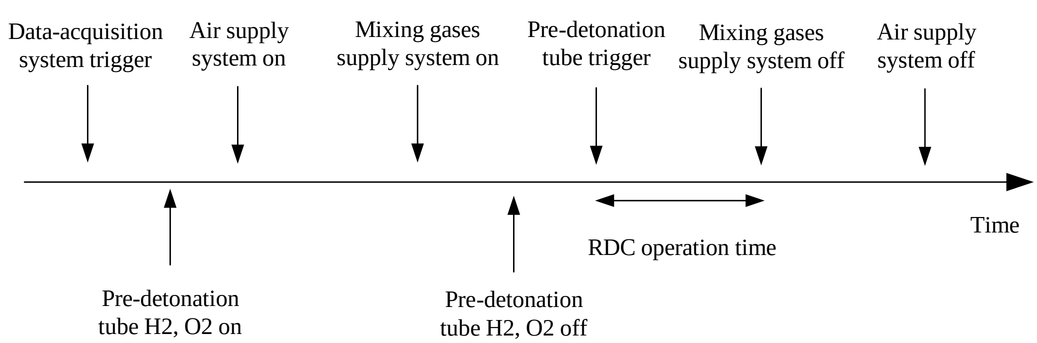

Fig 2 Time sequence of the experiments

The PCBs are installed to collect the high frequency pressure signal. The effect of the components of fuel, flow rates and equivalence ratio on the delay time were researched in this study. It should be noted that the delay time mentioned in this paper is defined as the time from the initial ignition to the formation of a continuous and stable detonation wave.

3 Results and discussions

(1) The effects of the mixture components

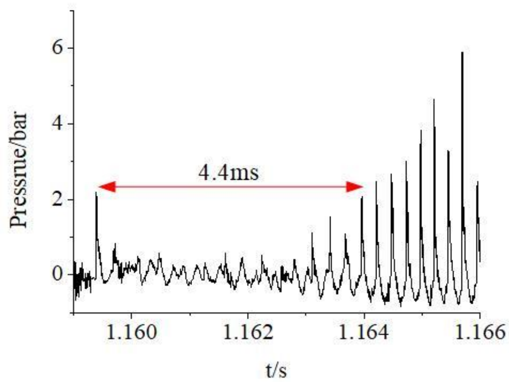

Fig 3.a Ethylene-acetylene-hydrogen-air

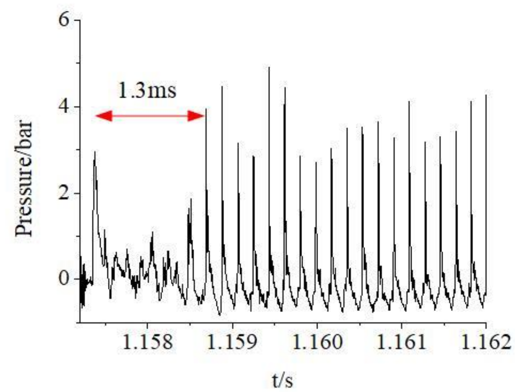

Fig 3.b Hydrogen-air

Fig 3 Delay time of rotating detonation with different gasous fuel-air mixtures

Fig 3 presents the delay time of rotating detonation with different gasous fuel-air mixtures. The equivalence ratios and flow rates are approximately the same in the two tests, and the RDWs are at stable conditions. It is indicated that the delay time of the ethylene-acetylene-hydrogen-air mixture (4.4ms) is longer than that of the hydrogen-air mixture (1.3ms). The reason for this phenomenon should be attributed to the higher activity of hydrogen than the ethylene-acetylene-hydrogen mixture, which accelerates the chemical reactions in the initiation process.

(2) The effects of the flow rates

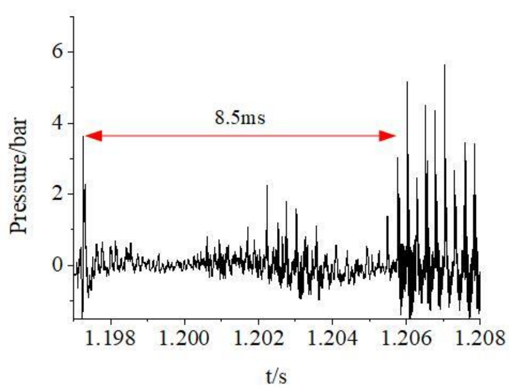

Fig 4.a Air flow rates = 256.6g/s

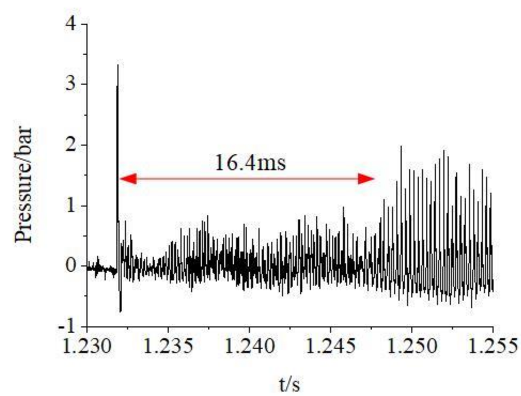

Fig 4.b Air flow rates = 202.5g/s

Fig 4 Delay time of rotaing detonation with different flow rates

Presented by Fig 4, the delay time under higher flow rates is decreased in an initiation process of the rotating detonation. This kind of decrease in the delay time may be attributed to the interaction between the combustor and plenum. The higher flow rates leads to a higher injection pressure and the recovering time for the plenum from the former detonation wave is shortened. Also, the increasing flow rates broaden the stable operating range of the rotating detonation, which make it easier to formate a stable RDW.

(3) The effects of the equivalence ratio

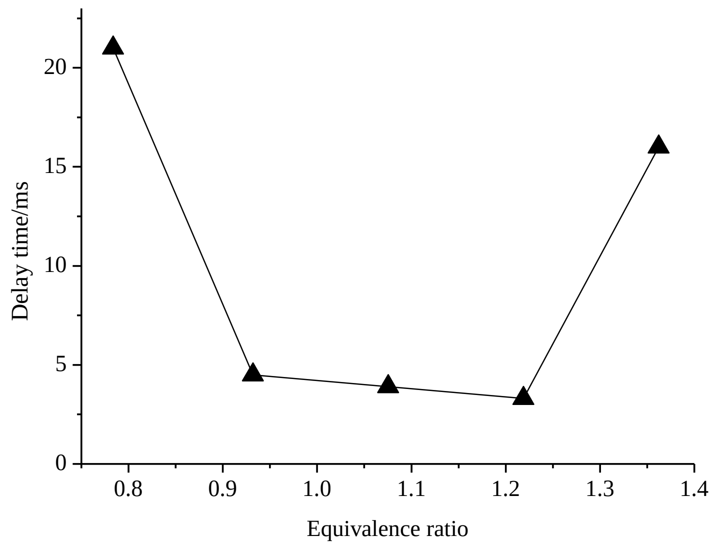

Fig 5 Delay time of rotaing detonation with different equivalence ratios

Fig 5 indicates that the delay time stablizes at a low level when the equivalence ratios near the stoichiometric ratio, and the delay time increase quickly when the equivalence ratios approach the stable operating boundary (floor at 0.64-0.78, ceiling at 1.2-1.3) . One reason for the changes of the delay time is the differences in activity under different equivalence ratios and the other is that the formation of an RDW is more difficult when the test conditions approach the stable operating boundary.

4 Conclusions

Experiments were conducted to investigate the effect of mixture components, flow rates and equivalence ratio on the delay time of the rotating detonation initiation. The results showed that the delay time decreased when the mixture activity increased and the equivalence ratio approached the stoichiometric ratio. The wider stable operating range at higher flow rates also could decrease the delay time of the initiation and the delay time in the stable operating range sustained at a low level.

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