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Research Paper

Ignition method effect on detonation initiation characteristics in a pulse detonation engine

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HIGHLIGHTS

- Three ignition methods were designed and investigated by experiments.
- The ignition and detonation initiation characteristics were analyzed and discussed.
- Operating frequency was improved when the length of jet pipe decreased.
- DDT distance was shortened to about 700 mm by pre-detonator ignition method.
- The detonation initiation time by pre-detonator ignition method was only 2~3 ms.

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ABSTRACT

The detonation initiation performance of a kerosene fueled air-breathing pulse detonation engine was investigated. Three ignition methods were investigated experimentally, including spark ignition, hot jet, and pre-detonator. The deflagration-to-detonation transition distance measured using the hot jet initiation method was 1130 mm, a reduction of approximately 150 mm compared to the baseline spark ignition method. As the length of jet pipe decreased to 100 mm, the detonation frequency increased to 35 Hz. The PDE operating frequency had little impact on detonation initiation time when pre-detonator ignition method was used, and there was a slight deviation error of detonation initiation time at each of the operating frequencies. However, when spark and hot jet ignition methods were used, detonation initiation time decreased at the increased operating frequency and the deviation error of detonation initiation time was much higher. The shortest detonation initiation time of 2–3 ms and deflagration-to-detonation transition distance of 700 mm were obtained using the pre-detonator ignition method.

1. Introduction

A pulse detonation engine (PDE) is an unsteady device that utilizes the expansion of the combustion products generated by the initiation of periodic detonation waves in a combustor to achieve thrust or power. Fundamental and applied PDE research has been a hot topic over the last two decades around the world because of its advantages of simple construction, high thermal cycle efficiency, and a wide operating range [1–4]. One of the key topics for PDE research is the implementation of low ignition energy to initiate stable detonation waves in a hydrocarbon–air mixture within a short distance and time [5]. Because of the high energy requirement to achieve direct detonation initiation, many researchers have investigated the use of a weak spark ignition in an optimally design geometry to promote deflagration-to-detonation transition (DDT) [6,7]. However, an impractical long run-up distance (and time) is usually required for DDT with this method. Furthermore, the reliability of weak spark ignition decreases under the condition of high speed incoming flow.

Nanosecond plasma ignition [8], multipoint successive ignition [3,9], jet ignition [10–16] and optical ignition [17] are all ignition methods investigated for multi-cycle operating condition. Transient plasma and laser focusing are both promising ignition technologies; however, there are limits associated with these complex systems and their practical adoption. In contrast, jet ignition is more practical for initiating the detonation in the main chamber. According to the condition of the exhaust jet, the hot jet ignition method can be classified into three categories: ignition methods of detonation jet, supersonic flame jet and subsonic flame jet. The detonation jet ignition is also sometimes called pre-detonator ignition.

A large amount of research has been performed looking at single-shot hot jet detonation initiation. Knystautas et al. [10] carried out an experimental study to establish the basic mechanisms of transition from deflagration to spherical detonation downstream of flow obstructions through stereoscopic streak and framing schlieren

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photography. Carnasciali et al. [11] investigated experimentally the hot jet detonation initiation of different stoichiometric fuel–oxygen mixtures with nitrogen dilution. The results suggested that under optimal conditions of initiation there existed a minimum value of the ratio of the orifice diameter *d* to the test mixture detonation cell size λ. Brophy et al. [12] found that the diffraction of the detonation wave when it propagated into the main detonation chamber and reduced the intensity of leading shock wave led to failure of direct detonation initiation. The weakened detonation formed hot spots that resulted in the indirect initiation of detonation in the main detonation chamber. Li and Kailasanath [13] explored the concept of initiating detonations using annular-jet-induced cylindrically imploding shocks.

The multi-cycle hot jet detonation initiation in multi-detonation chambers was investigated experimentally by Li and Yan [18]. Yu J. et al. [19] carried out an experimental study on DDT with hot jet ignition in a detonation tube fueled with acetylene/air mixture. Numerical simulations were carried out by Zeng et al. [20] to investigate the effects of the position and the filling speed of a transverse hot jet on detonation initiation process in a detonation tube. Wang et al. [21] performed numerical simulations investigating the effect of pressure, velocity and temperature of a transverse jet on the characteristics of detonation initiation. Cai et al. [22] investigated detonation initiation and propagation with a hot jet in nonuniform combustible mixtures by numerical simulation.

This paper investigates experimentally three ignition methods, including weak spark (spark plug) ignition, jet ignition and pre-detonator ignition, in a valveless air-breathing 110 mm inner-diameter pulse detonation engine. The length of "jet pipe" and the operating frequency effects on detonation initiation characteristics were also investigated with the same setup. The testing demonstrated reliable ignition and detonation initiation under the practical condition of high speed incoming flow.

2. Experimental setup

An air-breathing valveless two-phase PDE with an inner diameter of 110 mm consisted of inlet, mixing chamber, ignition chamber, detonation chamber and nozzle. A schematic of the experimental setup based on the air-breathing PDE is shown in Fig. 1. The liquid fuel of kerosene (Jet A-1) and air were introduced to PDE by adaptive control without valve. The operating frequency of PDE was controlled by the ignition frequency driven by a signal generator. For the air-breathing PDE, air was supplied upstream of the air inlet by a semi-free flow field. The nozzle with convergent ratio of about 0.64 was installed after the detonation chamber.

A twin-fluid air-assist atomizer was used for kerosene injection. When the pressure of assist air was about 0.3 MPa and the flow rate of gasoline was in the range of 0.6–2 L/min, the Sauter diameter of gasoline droplet at the position of 100 mm from the air-assist atomizer was 40–100 μm [5]. The droplet size decreased and some of the fuel droplets were vaporized after the fuel droplets were introduced into the detonation chamber due to the high temperature tube wall that resulted from the PDE multi-cycle operation.

The Shchelkin spiral with a pitch of 100 mm and a wire diameter of 14 mm was welded in the detonation chamber to accelerate DDT, and reduce DDT distance and time. The flow rates of the fuel and air were kept constant at the same operating frequency, and the equivalence ratio was 1. The air velocity in the inlet at the operating frequency of 10 Hz, 15 Hz, 20 Hz, 25 Hz, 30 Hz and 35 Hz was about 21 m/s, 33 m/s, 45 m/s, 56 m/s, 67 m/s and 75 m/s respectively.

This paper focused on three kinds of ignition methods. The first ignition method, as shown in Fig. 2a, was the spark plug ignition method with adjustable output ignition energy of 0–4 J. A spark plug was installed in the ignition zone with the inner diameter of 30 mm and length of 30 mm. The second ignition method of hot jet included two different jet pipes with the same inner diameter of 30 mm but different lengths of 200 mm and 100 mm. Kerosene and air mixture was introduced to the pipes by a siphon with the inner diameter of 10 mm but different lengths of 170 mm and 80 mm, while the flame generated in the pipes propagated into the main chamber through the annular channel, as shown in Fig. 2b. The last method was the ignition technology with small size pre-detonator. Gasoline (Octane Number 90) was used as the fuel, as shown in Fig. 2c, while kerosene was still used as fuel in the main detonation chamber. In all of the three ignition methods, the ignition energies for the initial spark plugs were about 0.5 J.

The pressure was measured along the length of the PDE at eight different transducer ports with piezoelectric pressure transducers (Type: CA-YD-205). The nonlinear and repeatability of the transducers were both less than 1% FS. The operating temperature of the transducers was –40 °C~+150 °C. The transducers were protected by the water cooling to ensure the operating temperature requirement. There was no engine cooling during the tests. Fresh air was introduced to the engine to cool it after each of the test was fin-

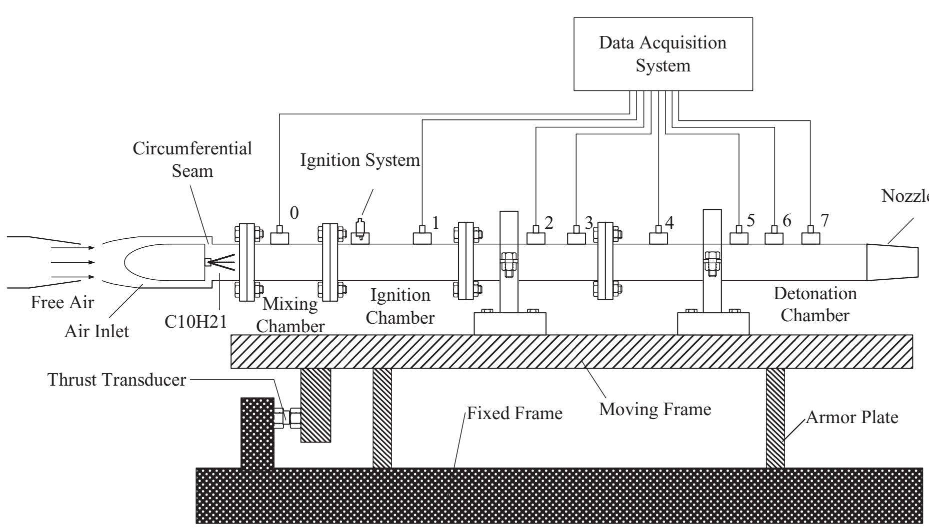

Fig. 1. Schematic of the air-breathing PDE test system.