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Ignition experiment with automotive spark on rotating detonation engine

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ABSTRACT

An experimental study on rotating detonation engine with the slot-orifice impinging injection method was presented in this paper. Reactants were gaseous H_2–Air mixtures and ignited by an automotive spark plug. The engine was initiated successfully and rotating detonation wave propagated continuously and steadily in the circumferential direction. Through the detailed analysis on the initiation and propagation process of rotating detonation wave, it was found that deflagration-to-detonation transition (DDT) was observed in the annular combustion chamber, and the DDT time exhibited an obvious randomness. For the operating conditions which the rotating detonation wave propagated stably, the fluctuation of the pressure spike of detonation wave was relatively small, and the detonation wave propagated continuously without interruption; for the operating conditions which the detonation wave was unstable, the fluctuation of pressure spike of detonation wave was relatively large, and the interruption occurred, which might result in the change of propagation direction of rotating detonation wave. And in some operating conditions, a new phenomenon that strong detonation and weak detonation occurred alternately was found. Besides, in order to obtain the success rate of rotating detonation wave initiation with automotive spark plug, repeatability experiments were carried out. The results show that the success rate was up to 94%.

Introduction

With the exploration and development for many years, the aerospace engine technology based on isobaric combustion mode had become gradually mature. So improving the propulsive efficiency significantly is very difficult. The development of new engine which satisfies the requirements of high speed and high efficiency becomes the urgent needs for aerospace field nowadays. Rotating detonation engine (RDE) is a new interesting propulsion technology that obtains thrust from continuous rotating detonation wave.

The schematic diagram of rotating detonation wave engine (RDE) is shown in Fig. 1. It is generally equipped with an annular combustion chamber, and the fuels are injected from the bottom of combustion chamber. A detonation wave and possibly multiple waves rotate in the annular combustion chamber just at the exit of the injector arrays, consuming the fresh reactants feeding continuously from the bottom [1]. Detonation is an extremely rapid isochoric combustion mode. So, compared to conventional jet engine based on the isobaric

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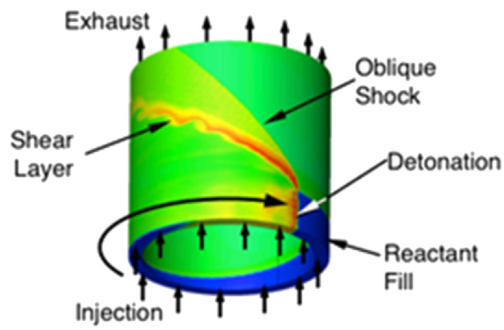

Fig. 1 – Typical flow field structure of RDE [2].

combustion mode, RDE has many advantages such as rapid energy release rate, high thrust-to-weight ratio, high volumetric efficiency and so on. All of these make the performance of RDE far outstrips the conventional engines based on deflagration and make RDE attractive for the researchers as a future aerospace propulsion system. Moreover, the detonation wave rotates in the annular combustion chamber, so the combustion waves just exist in some specific locations which means that the requirements for the reactants' spouting are always satisfied in some other locations of the annulus. The reactants of RDE are always fed continuously and products of detonation are exhausted continuously thus far indicate that RDE is self purging. Therefore, the feeding and purging are carried out in the same time. So only one initial ignition is needed to start the detonation wave. This makes the ignition system design of RDE greatly simplified, the weight and bulk both reduced, and life of the igniter obviously increased. Besides, even if in the condition of low-speed inflow, the RDE also can work normally. RDE also can achieve the thrust vectoring control by adjusting the reactants mass flow rate of the different circumferential locations. Therefore, RDE has attracted considerable attention in the recent years.

The research on RDE began in the 1950s, Voitsekhovskii [3–5], Mitrofanov [6] and Topchiyan performed experiments on rotating detonation in oxy-acetylene mixtures and they were able to stabilize the rotating detonation in the annular combustion chamber for a relatively long duration [7,8]. If we review the research history of the past years, the simplest means of initiating the RDE is to ignite a spark plug, predetonator [9,10], exploding wire [11], or electric detonator and explosive mass in either the channel or one of its side walls. The ignition source causes waves to form, which quickly transit to shock and/or detonation waves. The repeatability of this method was proved to be relatively low. For instance, Kindracki [12–14] performed series experiments on rotating detonation in air-acetylene mixtures by the ignition of automotive spark plug, and the success rate was verified to be 40%.The same engine with a pre-detonator and diaphragm had 95 percent repeatability [1]. Igniting directly in the annular combustion chamber may be lead to the two detonation waves propagating in two opposite circumferential directions, and the two detonation waves will conflict with each other in the other side of the channel which makes the detonation decouple. Nicholls [15,16] and Cullen installed a partition device in the annular channel to impose restrictions on the propagating direction. The partition device prevented the detonation wave from propagating in more than one direction from the point of ignition successfully, and the detonation wave propagated along the specified direction. The success rate of this method was verified to be greatly improved. However, the partition made the structure of the engine much more complex, and it also limits the restarting of the engine. So the issue on starting and establishment of the detonation wave wasn't solved essentially. Thomas [17] and Canteins [18] incorporated a pre-detonator on RDE to emit a detonation wave into the annulus tangentially, and a single detonation wave propagating in one direction was obtained [19], a rarefaction or weak shockwave generated in the other direction. A valve was placed at the exit end of the perdetonator so it could be refilled to restart the engine [1]. While LIU Shijie [20] found that there was a time interval from the ignition to the establishment of the detonation, and the time interval was caused by the exhausting process of the combustion products in the pre-detonator. From the literatures published, we know that various initiation methods were applied to initiate the rotating detonation wave, and the researchers have obtained some achievements. Both the requirements for the detonation initiation and the formation mechanism of detonation wave were not completely clear. The way that the detonation waves are ignited, sustained and stabilized are not well reported even with the recent upsurge of RDE studies [1]. The initiation methods mentioned before all have some insufficiencies such as the low repeatability, complex structure and so on.

In order to explore a simple and practical initiation method for the RDE, a low energy automotive spark plug with 30 mJ is applied to ignite the RDE directly. The feasibility of this method is discussed and validated in this paper. At the same time, based on the pressure data recorded by the transducers, a great deal of analysis on the detonation establishment process and stable operating process are carried out. Besides, the initiation success rate has been investigated experimentally, and a detailed analysis on the DDT time and the average propagating velocity of detonation wave is presented in this paper.

Experimental setup

The RDE is ignited directly by an automotive spark plug in this paper, thus the initiation system is greatly simplified. The experimental system of RDE is shown in Fig. 2 and it is mainly composed of the reactants supply system, experimental engine, initiation system, and data acquisition system. The fuel is H_2, and the oxidant is air. The reactants are fed either separately into two different plenum chambers designed in the front half of the engine and then are spouted into the annular combustion chamber from the bottom of the plenum chambers. The mass flow rates of the reactants are controlled through the combination of pressure regulators and sonic nozzles on the feed lines. Two magnetic valves are used to quickly turn on and off the fuel and oxidant flows respectively while two manual shutoff valves are used for safety [17]. The mixing and the combustion of reactants carry on in the annulus at the same time, so the mixing effect of H_2–Air is of