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Experimental study of slight temperature rise combustion in trapped vortex combustors for gas turbines

R.C. Zhang [a, *], W.J. Fan [a], F. Xing [b], S.W. Song [c], Q. Shi [a], G.H. Tian [d], W.L. Tan [a]

[a] National Key Laboratory of Science and Technology on Aero-Engines Aero-Thermodynamics, School of Energy and Power Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100191, China
[b] School of Physics and Mechanical and Electrical Engineering, Xiamen University, Xiamen, Fujian 361005, China
[c] China Aviation Powerplant Research Institute, Aviation Industry Corporation of China, Zhuzhou, Hunan 412002, China
[d] Department of Mechanical Engineering Sciences, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford GU2 7XH, UK

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A B S T R A C T

Interstage turbine combustion used for improving efficiency of gas turbine was a new type of combustion mode. Operating conditions and technical requirements for this type of combustor were different from those of traditional combustor. It was expected to achieve engineering application in both ground-based and aviation gas turbine in the near future. In this study, a number of modifications in a base design were applied and examined experimentally. The trapped-vortex combustion technology was adopted for flame stability under high velocity conditions, and the preheating-fuel injection technology was used to improve the atomization and evaporation performance of liquid fuel. The experimental results indicated that stable and efficient combustion with slight temperature-rise can be achieved under the high velocity conditions of combustor inlet. Under all experimental conditions, the excess air coefficients of ignition and lean blow-out were larger than 7 and 20, respectively; pollutant emission index of NO_x and the maximum wall temperature were below 2.5 g/(kg fuel) and 1050 K, respectively. Moreover, the effects of fuel injection and overall configuration on the combustion characteristics were analyzed in detail. The number increase, area increase and depth increase of fuel injectors had different influences on the stability, combustion characteristic and temperature distribution.

1. Introduction

Interstage turbine combustion was a new type of gas turbine combustion, it was proposed for improving the efficiency of energy conversion [1,2]. Interstage turbine combustor was installed between high-pressure turbine stage and low-pressure turbine stage of gas turbine. It was used to raise the gas temperature of low-pressure turbine inlet, and it has proven to effectively improve the efficiency and power of gas turbine based on the results of theoretical analysis [2–4]. This technology is still in the early stage, and it is expected to achieve engineering application in the near future.

Operating conditions and technical requirements of the interstage turbine combustor were different from those of traditional main combustor and after-burner of gas turbine. The schematic diagram of gas turbine was shown in Fig. 1. Compared with the main combustor, the temperature rise between the outlet and inlet of the interstage turbine combustor was very small, and it should usually not exceed 300 K. At the same time, the inlet Mach number of interstage turbine combustor was up to 0.5, which was much higher than that of main combustor. The characteristics of slight temperature rise and high inlet velocity increased the combustion instability in the combustion zone.

Compared with the after-burner, the requirements for outlet-temperature distribution uniformity of interstage turbine combustor were very strict, which was due to consideration of the service life of low-pressure turbine. Since the interstage turbine combustor was a continuously working component, maximum temperature and temperature gradient of combustor liner must be strictly controlled in the allowable range of the material. Moreover, the length of interstage turbine combustor should be short enough to ensure the safety of rotor of gas turbine. In order to meet these requirements, new type of combustion mode need to be adopted.

Using the mode of trapped vortex combustion, stable combustion with high efficiency can be achieved under high velocity

* Corresponding author. Tel.: +86 10 82317422; fax: +86 10 82316909.
E-mail address: zhangrongchun@buaa.edu.cn (R.C. Zhang).

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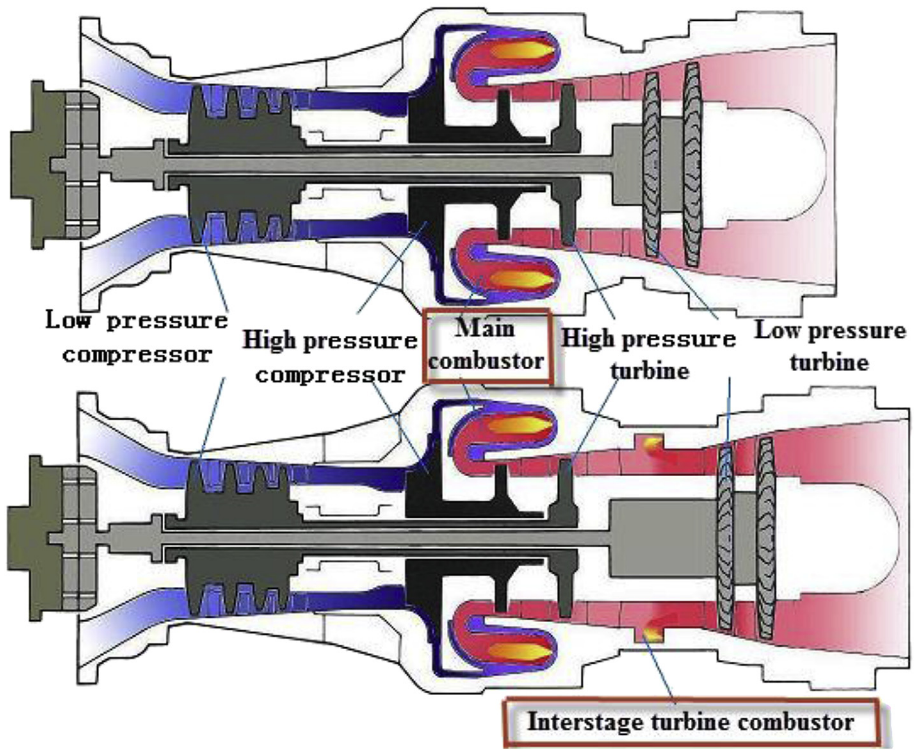

Fig. 1. The schematic diagram of gas turbine [5].

condition at combustor inlet [6,7]. Gas turbine combustor adopted recirculation zone to stabilize flame, and this zone in conventional combustor was usually created and maintained by rotational flow. But trapped vortex combustor adopted the cavity to establish recirculation zone and organize the combustion process in the cavity zone [8–11]. After years of research, it has been demonstrated that there are wider operating range, higher combustion efficiency and lower emissions for trapped vortex combustor with compact configuration [12–15]. Moreover, the operating conditions of combustor and the injection modes of fuel and air had a large influence on the overall performance of trapped vortex combustor [16,17].

Based on the technology of trapped vortex combustion, the interstage turbine combustor can be expected to satisfy the strict requirements mentioned above. The relevant research has been carried out by our research group since 2006 [6,18,19]. The influences of air and fuel parameters on combustion stability of a 2D interstage turbine combustor have been studied experimentally. Results showed that combustion stability can be achieved under high inlet velocity of combustor inlet.

For general combustor of gas turbine, each combustor had various requirements of performance, and there were some apparent contradictions between these requirements [20,21]. The results from research on the influences of important parameters on the performance were the key bases of structural design for gas-turbine combustor.

This paper presents a number of modifications in a base design for interstage turbine combustion. Using single-cavity configuration and preheating fuel injectors, highly efficient and stable combustion was achieved under the condition of slight temperature rise and high inlet velocity. This paper reports a detailed study of the influences of various factors on the combustion characteristics using experimental method. The feasibility of the structural scheme was analyzed with attention to overall performance, including combustion stability, combustion characteristics, temperature distribution, and so on. The results can be used for structural design and optimization purposes.

2. Experimental method

2.1. Configuration of model combustors

The model combustors fueled with aviation kerosene were shown in Figs. 2 and 3. They were mainly composed of cavities and shells. After the mainstream of air flowed into the combustor, the air was divided into two parts by the cavity. A part of the air flowed along the channel of mainstream, and the other part of the air flowed into the external channel of the combustor. Then the latter part of the air was divided into several categories: 1) Air entered the cavity zone through several rows of intake holes in the wall of cavity, which will help to the formation of trapped vortex and the cooling of cavity wall; 2) Air entered the mainstream through several rows of dilution holes in the wall of mixing section, which will contribute to the temperature-distribution uniformity of outlet.

Preheating fuel injectors were located in the upper left of the combustion zone. Fuel injection direction was consistent with the

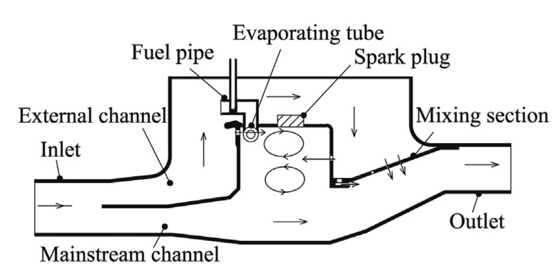

Fig. 2. The schematic diagram of interstage turbine combustion.