Applied Thermal Engineering 62 (2014) 662–670

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

An experimental study of fuel–air mixing section on unstable combustion in a dump combustor

Min-Ki Kim [a,b], Jisu Yoon [a], Jeongseog Oh [c], Jongguen Lee [d], Youngbin Yoon [a,*]

[a] School of Mechanical and Aerospace Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea
[b] Power System R&D Center, Samsung Techwin Co. Ltd., Gyeonggi-do 463-400, Republic of Korea
[c] Energy Efficiency Center, Korea Institute of Energy Research, Daejeon 305-343, Republic of Korea
[d] School of Aerospace System, University of Cincinnati, 2901 Woodside, Cincinnati, OH 45221, USA

HIGHLIGHTS

- Instability modes have been accurately analyzed by multi-channel p' sensing system.
- Major instability parameters are known to be φ, v_{mix} and combustor, plenum geometry.
- The 1st mode was associated with fundamental longitudinal mode of combustor section.
- The 2nd mode was acoustically coupled with the combustor and inlet mixing section.
- The Instability was strongly affected by acoustic coupling with combustor and plenum.

ARTICLE INFO

Article history:
Received 7 July 2013
Accepted 17 September 2013
Available online 25 September 2013

Keywords:
Gas turbine
Combustion dynamics
Inlet mixing section
Multi-channel dynamic pressure
OH chemiluminescence

ABSTRACT

The main objective of this study is effect of the various fuel–air mixing section geometries on the unstable combustion. For the purpose of observing the combustion pressure oscillation and phase difference at each of the dynamic pressure results, the multi-channel dynamic pressure transducers were located on the combustor and inlet mixing section. By using an optically accessible quartz-type combustor, we were able to OH* measurements to characterize the flame structure and heat release oscillation with the use of a high-speed ICCD camera. In this study, we observed two dominant instability frequencies. Lower frequencies were measured around 240–380 Hz, which were associated with a fundamental longitudinal mode of combustor length. Higher frequencies were measured around 410–830 Hz. These were related to the secondary longitudinal mode in the combustion chamber and the secondary quarter-wave mode in the inlet mixing section. These second instability mode characteristics are coupled with the conditions of the combustor and inlet mixing section acoustic geometry. Also, these higher combustion instability characteristics include dynamic pressure oscillation of the inlet mixing section part, which was larger than the combustor section. As a result, combustion instability was strongly affected by the acoustically coupling of the combustor and inlet mixing section geometry.

© 2013 Published by Elsevier Ltd.

1. Introduction

As a high-efficiency and low-pollution engine, a gas turbine is utilized for various different uses, ranging from the aviation industry to the electric power generation industry [1,2] and RQL (Rich burn Quick mix and Lean burn) type combustion [3,4] quickly became important. As a result, the emission of NOx could be sharply decreased, but another problem arose in this context, which was that the flame became unstable in extreme reaction to the external disturbance. The combustion instability indicates that the local change of unsteady heat release waves and acoustic waves from the combustion chamber interact with each other, further generating a fluctuation of specific instability frequency. The fluctuation of unstable dynamic pressure generates a perturbation of fuel–air mixture flow, and then this fluctuation generates a perturbation of heat release waves, thus developing into the phenomenon of combustion instability. When the combustion instability characteristic takes place, it is able to satisfy the Rayleigh criterion theory [5], as formulated here:

* Corresponding author. School of Mechanical and Aerospace Engineering, Seoul National University, New Engineer Bldg. 301-1301, 599 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea. Tel.: +82 2 880 1904; fax: +82 2 887 2662.
E-mail addresses: ybyoon@snu.ac.kr, dedoo23@snu.ac.kr (Y. Yoon).

1359-4311/$ – see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.applthermaleng.2013.09.030

$$\int_0^{\tau}\int_0^{V} p'(x,t)\cdot q'(x,t)\mathrm{d}V\,\mathrm{d}t > \int_0^{\tau} \phi(x,t)\mathrm{d}V\,\mathrm{d}t \tag{1}$$

The combustion instability mode is attributed to various other factors, such as heat release oscillation [6] by the flame vortex and acoustic pressure boundary formation with other space except the combustor, as well as the internal configuration of the combustor [7–10]. For instance, the GE 7FA + e DLN-2.6 is used to stabilize the combustion. In the initial stage of combustion, a high level of NOx is generated in the section called Mode 3 (10–20 MW). In the section of Mode 6B (20–45 MW), which leads to the maximum output, this has a feature that the engine combustion oscillation is caused by the conversion into the premixed mode. At this moment, through the frequency of combustion instability, although the combustor temperature increases in proportion to the output increase in speed, there is no change in the instability frequency, and it is sustained as 120–140 Hz [11] Since the instability frequency does not increase as the temperature of the combustion chamber increases, we discovered that the instability mode, which is appears as an acoustic pressure field, is formed not by the combustor mode but other geometric characteristics [12,13].

Previous studies were conducted to observe the phenomenon of combustion instability and flame structure [14,15] in the combustor having a simple fuel nozzle with the swirl effect and to investigate a method of analyzing the cause and mode of combustion instability [16,17]. Based on the results of the previous studies, however, this study observed the phenomenon of combustion instability by changing the combustor length and its fuel–air mixture velocity to discover the characteristics of the combustion instability mode and their kinds in a combustor simulating an actual gas turbine for power generation. At this point, this study confirmed the conditions of heat release oscillation by changing the fuel–air mixture velocity and equivalence ratio and verified the exact causes of combustion instability by analyzing the instability modes and phases appearing during the combustion instability by multi-channel dynamic pressure sensing measurement [18] in both the combustor and the inlet mixing section.

2. Experimental apparatus and conditions

2.1. Model dump-shape gas turbine combustor

The combustor used for this study is a 1/3 scale model gas turbine combustor simulating the GE 7FA + e DLN-2.6 gas turbine combustor, which is characterized with premix and a swirl-stabilized flame as shown in Fig. 1. The combustor is composed of an air-heating device, air supply lines, fuel nozzles, a flame visualization quartz combustor and a spike-typed plug nozzle for the exhaust duct as an acoustic boundary. The air-heating device consists of three 40 kW class electric heating elements, functioning to heat the supplied air up to 873 K. As one of the main variables for this experimental study (as shown in Table 1.), the fuel–air mixing section was located between the combustor dump-side and the choking orifice at the back of the air-heating device, which came in three lengths, 470, 550, and 870 mm, although all inlet mixing section had an inner diameter of 40 mm. The swirl injector used for this device is an axial-typed injector, which has 10 swirl vanes set at the angles of 0° and 30°. Fuel is injected at 20 mm detached spot from the swirl vane, 10 nozzles, each of which has a 1.2 mm-sized hole, and is premixed with air through the 140 mm-sized mixing length. The swirl effect can be calculated approximately through the following equation [19]:

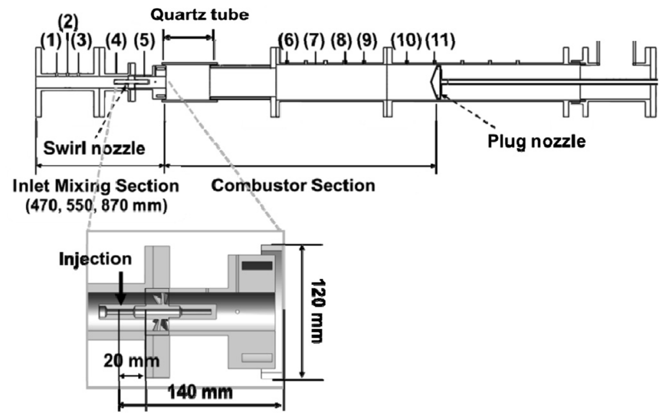

Fig. 1. Schematic of model gas turbine combustor and location of dynamic pressure sensors.

$$S = \frac{2}{3}\left[\frac{1-(d_h/d)^3}{1-(d_h/d)^2}\right]\tan\theta \approx \frac{2}{3}\tan\theta (d_h << d) \tag{2}$$

According to the above equation, the swirl number of the swirl injector used for this research was about 0.42. A circular stainless steel (@ case 1, 2) and a quartz tube (@ case 3–8) for the flame visualization were alternately used, and the diameter inside the combustor was 120 mm. The plug nozzle placed at the exhaust duct was supposed to function to change the resonant frequency of the combustor by making an acoustic boundary that blocks 91% of the combustor exhaust duct, which was designed to regulate the length of the combustor by 0.1 mm from 800 mm to 1680 mm through the stepper motor located in the exhaust part of model gas turbine combustor.

2.2. Combustion data acquisition system

To measure the flow rate of fuel and air, we used high resolution digital mass flow meters (Brooks). A K-type thermo couple was used to measure the temperatures of eight channels in total consisting of the air supply (3 each), the combustor (4 each), and the exhaust emission sensor location (1 each), as well as the temperature around the differential pressure gauge for the regulation of the fuel and air flow rate. To observe the oscillation of dynamic pressure occurring during the combustion experiment, we used five 102A05-type dynamic pressure sensors (PCB), for the inlet mixing section and six for the combustor, as well as infinity probes, which suppress the reflected wave of dynamic pressure [20,21]. In addition, the sampling rate was observed by receiving 10,000 data per second, and through Fast Fourier Transformation (FFT) techniques, it was possible to analyze them up to 5000 Hz. The location of each dynamic pressure sensor is shown in Fig. 1. Moreover, OH

Table 1
Experimental case for various combustion instability conditions.

Test case	Injector type	Combustion instability mode	Inlet length [mm] (plenum)	Combustor length [mm]	Mixture velocity [m/s]	Equivalence ratio (Φ)
Case 1	No swirl	1L	470	1000	70	0.9
Case 2	No swirl	2L	470	950	70	1.1
Case 3	30° swirl	1L	470	1000	70	1.1
Case 4	30° swirl	2L	470	950	40	1.2
Case 5	30° swirl	1L	550	1050	70	1.0
Case 6	30° swirl	2L	550	950	40	1.1
Case 7	30° swirl	1L	870	1650	60	1.1
Case 8	30° swirl	2L	870	1650	70	0.8

Download English Version:

https://daneshyari.com/en/article/646381

Download Persian Version:

https://daneshyari.com/article/646381

Daneshyari.com