Pre-detection Study of Combustion Instability Using Dual-Nozzle Swirl Combustor and Classifying Criteria

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1 Introduction

In state-of-art gas turbines for thermal power generation or aviation, fast detection of combustion stability has recently faced challenges due to the rising techno-economical demand of decarbonized fuels and new high efficient ultra low NOx gas turbine combustors. Combustion instability (CI) accidents cause nozzle burnout with facility shutdown lasting at least several months and even human injuries [1]. New decarbonized fuels such as hydrogen have different combustion properties of adiabatic flame temperature, laminar burning velocity and explosive limit. Thus, because of these difference from existing combustion facilities, additional research in new combustion characteristics and combustion instability is needed.

One of the potential requirement to adapt new fuel is low level of combustion instability. To maintain low combustion instability, pre-detection of CI and control of air and fuel flow condition is very important. The intersection of RMS (Root Mean Square) of dynamic pressure law data and the static pressure (p') in combustor is used for existing combustion instability classification method. But in drastically changed new combustion environments, this method shows slow response and may cause mismeasurement when applicating new fuel and new structured combustors. For safe operation of the combustor for new fuels, several new concepts of combustion instability detection with criteria selection are applied to a dual-nozzle gas turbine combustor (DNGC), and their performance of combustion instability detection is compared in terms of the detection accuracy and detection speed.

2 Combustion Instability Classification Criteria

In this study, the intersecting point of RMS and p' and recently proposed combustion instability classification criteria, PE (Permutation Entropy), EoE (Energy of Entropy), ZCR (Zero-Crossing Rate)

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and Spectral Spread (SpS) are compared [2~6]. PE and EoE utilizing dynamic pressure entropy and Shannon entropy and classified combustion instability. The equation for PE is as below:

$$PE = -\sum P^k \log_2 p^k$$

P^k is the number of possible pattern.

The equation for EoE is as below:

$$EoE = -\sum_{i=1}^{n} P_i \log_2 P_i$$

n is the number of combustion dynamic pressure data, and Pi is ratio of events/total energy.

ZCR is a criterion for determining combustion instability starting time while counting the frequency of crossing the x-axis of the dynamic pressure. Because ZCR has no units, the standard deviation of ZCR (ZCR_{STD}) was used for precise comparison.

The ZCR and ZCR_{STD} equations are as below:

$$ZCR_i = \frac{1}{2n}\sum_{n=1}^{N-1}|S[x_i(n)] - S[x_i(n+1)]|,\ S[x_i(n)] = \begin{cases} 1, x_i(n) \geq 0 \\ -1, x_i(n) < 0 \end{cases}$$

$$ZCR_{STD} = \sqrt{\frac{\sum_{i=1}^{n}(ZCR_i - \overline{ZCR})^2}{n'}}$$

In ZCR equation, where n is the order of dynamic pressure signal, N is the total number of measured dynamic pressure. $x_i(n)$ is the n-th signal in the i-th frame, S is the factor of signal and i is the order of frame. In ZCR_{STD}, n' is the number of ZCR data.

SpS is a criterion indicating how widely single mode frequency dynamic pressure is distributed. Thus, SpS is suitable for a single-mode frequency combustion flame, not multi-mode frequencies.

The SpS equation is as below:

$$SpS = \sqrt{\frac{\sum_{i=1}^{n}((f_i - (c_{sp} \times 2/f))^2 \times amp_i}{\sum_{i=1}^{n} amp_i}}/(f_s/2)$$

where f_i is i-th frequency of dynamic pressure data, amp_i is the magnitude of f_i, and f_s is sampling frequency.

3 Experimental Setup

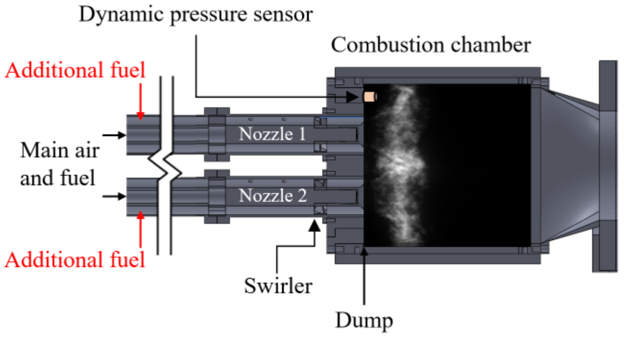

Figure 1: Schematic of a dual-nozzle gas turbine combustor.

Table 1: Experimental conditions of dual-nozzle gas turbine combustor.

Type	Dual-nozzle swirl burner
Measurment dynamic sensor model	PCB #102A05
Combustor length [mm]	1500
Experimental time [Sec]	3.5
Supply airflow temperature [ºC]	20
Combustor static pressure [kPa]	101.325 (Atmospheric pressure)
Swirl number [-]	0.8
H_2 composition [vol. %]	Nozzle 1: 0~40, Nozzle 2: 0
Equivalence ratio [-]	0.8

Combustion experiments using DNGC were conducted according to injected premixed fuel (CH_4 and H_2) [7]. Combustor's schematic and experimental conditions are shown in Fig. 1 and Table 1.

4 Results and Discussions

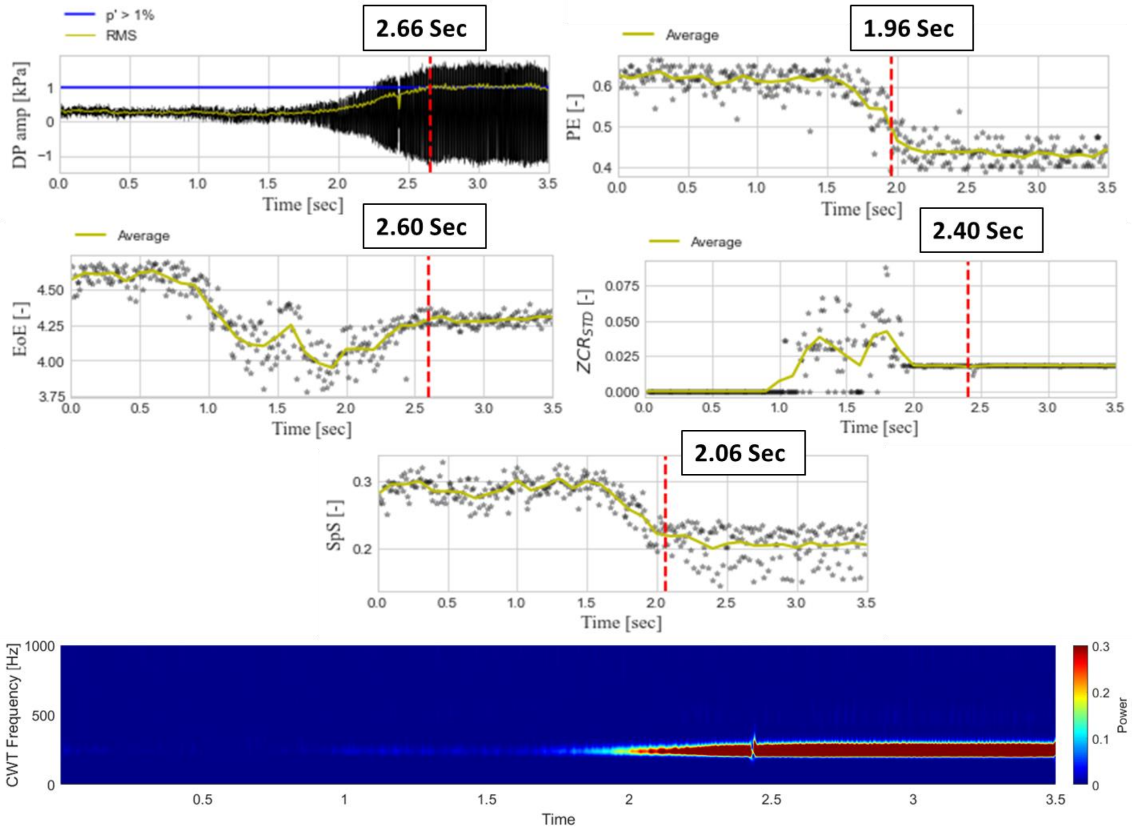

Figure 2: Combustion instability classifying criteria comparison(RMS & p', PE, EoE, ZCR, SpS) and CWT result.

In the experimental cases, stable to unstable transient data is applicated by five classification criteria and continuous wavelet (CWT). Experimental results are shown in Fig. 2. Red dotted line in Fig. 2 indicate that criteria distinguished the starting time of combustion instability, and this line utilizing time constant (*0.7071) of stable combustion data and unstable combustion data. Due to hydrogen fuel characteristics occurred multi-mode flame, this study conducted CWT. In CWT, single mode flame(230 Hz) was generated, can acquire high adequacy result of SpS.

Also, some results show rapid change at 1.6 Sec. This phenomenon is distinctly found in EoE and ZCR_{STD}, and this is confirmed due to dual nozzles.

4 Conclusions

In this study, experimental results according to combustor structure and classifying combustion instability were compared and investigated. As a result of the experiment, classifying speed of criteria is in the order PE > SpS > ZCR_{STD} > EoE > RMS & p'. But mutual comparison through application of other distinguishment methods besides the time constant is necessary. In experimental graphs, the phenomenon at 1.6 seconds was caused by injected fuel and structure difference of dual nozzles. Because this phenomenon affected time constant calculation, new classification methods are investigated.

5 Acknowledgment

This research was supported by Korea Electric Power Corporation. (Grant number: R22XO02-06). and this research was supported by Korea Electric Power Corporation (Grant number: R20XO02-34).

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