EXPERIMENTAL STUDY OF EQUIVALENCE RATIO INFLUENCE ON THERMO-ACOUSTIC INSTABILITY IN GAS TURBINES

Nasser SERAJ MEHDIZADEH[1,2,*] (Assistant Prof.), Nozar AKBARI[1,2] &
Reza EBRAHIMI[3] (Assistant Prof.)
[1] Aerospace Eng. Dept. - Amirkabir University of Technology
[2] Center of Excellence in Computational Aerospace Engineering
[3] Aerospace Eng. Dept. - Khaje Nasir Toosi University of Technology Tehran, Iran
(*Corresponding author: seraj@aut.ac.ir)

ABSTRACT

Premixed combustion is widely used for simulation of combustion chambers of gas turbines, utilized for low NOx emission applications. However, this category of gas turbines is susceptible to combustion instability. In this regard there are limited works, which are performed recently. Therefore, the maim aim of this investigation is focused on the influence of equivalence ratio on thermo-acoustic instability in gas turbine combustion chambers. An experimental approach is applied for this study.
For this purpose, an experimental combustion chamber is designed and fabricated and various experiments are planned and performed in order to achieve the better understanding of combustion chamber behavior during stable and unstable operations. Moreover, the experimental results are compared with Rayleigh criterion, which demonstrated good agreement between them.
In order for identifying instable conditions, state space distributions of the pressure oscillations are depicted for diverse operating conditions.

Keywords: Combustion Instability- Gas Turbines- Premixed Combustion- Thermo-acoustic instability

INTODUCTION

By using LPM1 technology, flue gas temperature is reduced, properly, in order to limit the amount of NOx emission [1]. Nevertheless, the pressure oscillation, which is produced by the coupling between unsteady heat release and acoustic pressure, may cause thermo-acoustic instability problem [2]. Pressure fluctuations always exist in a practical gas turbine combustion system, even in the stable mode of operation [3]. The fluctuations may sustain in the form of small amplitude oscillations, which are called classical acoustic motions, and the most important factor, affecting corresponding frequency, is combustor geometry [4].

EXPERIMENTAL SETUP

In order to perform experiments in the field of LPM combustion chambers, the setup, as shown in figure 1, is designed and fabricated.
In this research propane and air are employed as fuel gas and oxidizer, respectively. Different experiments are performed by changing equivalence ratio within the range of 0.7 to 1.5. Moreover, mass flow rate of fuel gas and air mixture is varied between 2 to 4 *gr/s*.
Sensible microphone is implemented for measuring the sound pressure level, generated during the tests. It should be noted that the pressure inside the combustion chamber is maintained at 1 atm, during all tests. It is observed that for the most cases, the combustion chamber becomes unstable when fuel air ratio is lean.

[1] Lean Pre-Mixed

RESULTS

In this research the first longitudinal mode of oscillations is studied. During the tests, fuel flow rate is kept constant at 5.6 l/min and air flow rate is varied between 116 to 172 *l/min*. Accordingly, equivalence ration is changed within the range of 0.7 to 1.15.

Figure 2 shows that the frequency of oscillations varies in the range of 225 to 250 *Hz*. It is worthy to mention that the higher frequencies correspond to the lower equivalence ratios, so that, decreasing the equivalence ratio, increases oscillations frequency, proportionally.

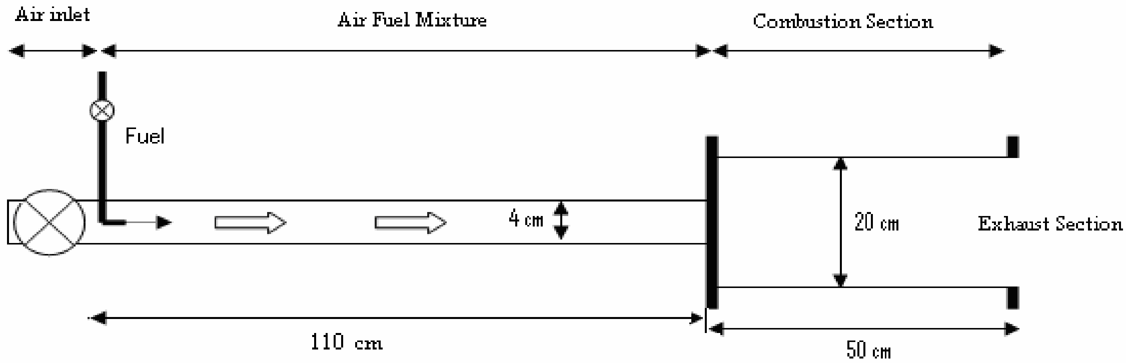


Figure (1): Schematic drawing of experimental combustion chamber

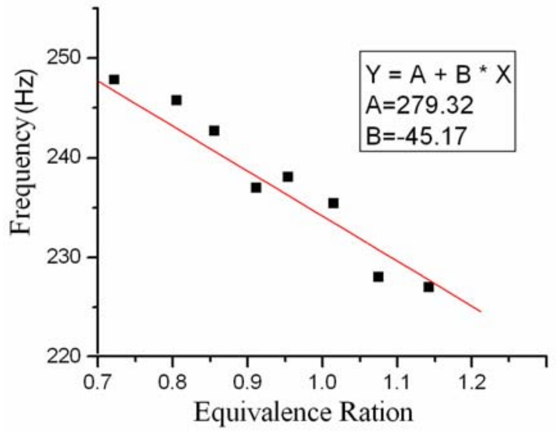


Figure (2): Relationship between equivalence ration and oscillations frequency

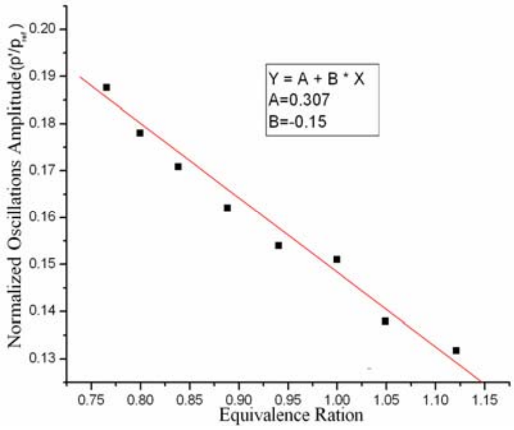


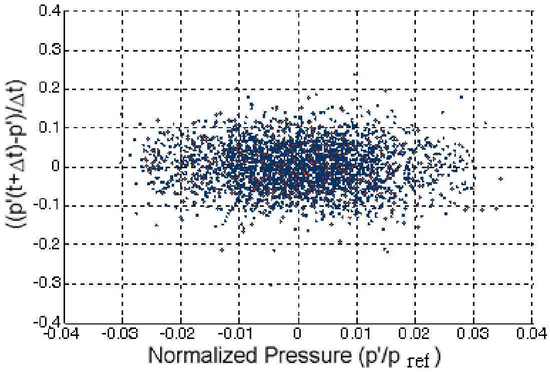
Figure (3): Variation of oscillations amplitude based on equivalence ratio

Variation of normalized pressure oscillations amplitude based on equivalence ratio is demonstrated in figure 3. It can be seen that oscillations amplitude decreases by increasing equivalence ratio, and this variation is, approximately, linear.

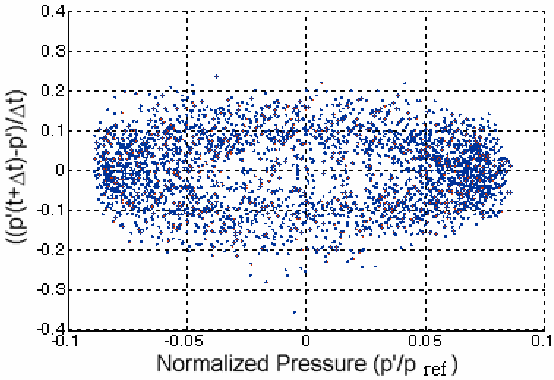
Figures 4, 5, 6 and 7 illustrate the state space distribution of the pressure oscillations based on the normalized pressure oscillations amplitudes, for equivalence ratios of 1.2, 1.1, 0.9, and 0.8.

As can be confirmed by using figures 4, 5, and 6, decreasing the equivalence ratio from 1.2 converts the state space distribution of the pressure oscillations to ellipsoid, and further reducing of equivalence ratio results in expanding the ellipsoid. The reason is expanding the ellipsoid is increasing the pressure oscillations amplitude.

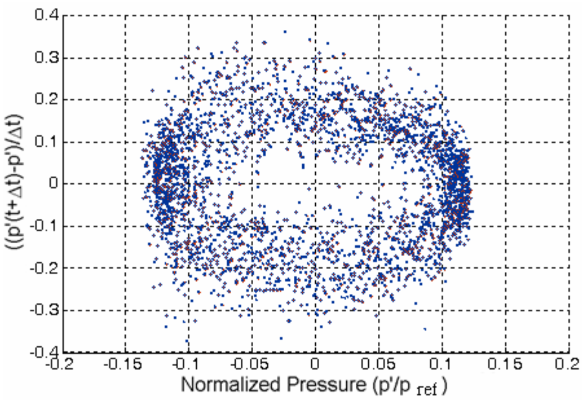
Unstable operation range, resulted from both methods, experimental data and Rayleigh criterion, is shown in figure 7. As it can be seen the range of τ/T for unstable operation based on Rayleigh criterion is 10.75 to 11.25 which is comparable with the experimental results.



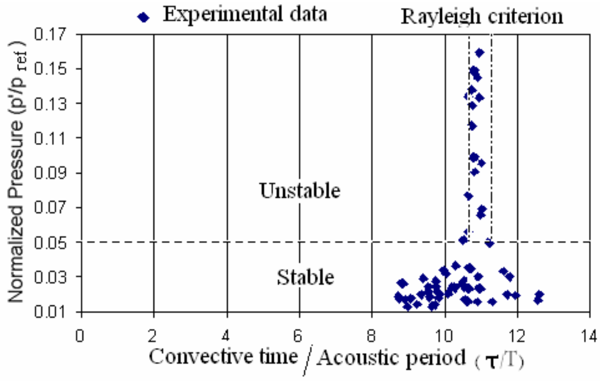
Figures (4): State space distribution of the pressure oscillations $(\phi = 1.2)$



Figures (5): State space distribution of the pressure oscillations $(\phi = 1.1)$



Figures (6): State space distribution of the pressure oscillations $(\phi = 0.8)$



Figures (7): Unstable operation range of τ/T resulted from Rayleigh criterion and experimental data

CONCLUSION

The outcomes of this research include experimental data resulted from LPM combustion chamber. The achieved results showed that there is close dependence between pressure oscillations frequency (and amplitude) and equivalence ratio. For the studied cases state space distribution of the pressure distribution are derived. It is shown that the mentioned state space distribution of the pressure diagram is concentrated around the center, but for unstable conditions this diagram transforms to ellipsoid. Moreover, reducing the equivalence expands the ellipsoid. Furthermore, the experimental results are compared with the result of Rayleigh criterion and good agreement is detected.

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