외부압력 교란에 의한 연소반응 연구 고찰

서성현*†

Study of Flame Response Characteristics to External Acoustic Perturbations

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ABSTRACT

It is critical to assess the characteristics of flame response to pressure perturbations for the understanding of nonlinear combustion instabilities. Previous studies can be grouped into flame response upon perturbed, fresh air and fuel mixture, and flame response directly perturbed from longitudinal waves. The present study presents experimental methodology for the understanding of the flame response exposed to transverse acoustic waves generated by loud speakers.

초 록

비선형적인 연소불안정 현상 이해를 위해서는 압력 섭동에 대한 화염 반응 특성 파악이 중요하다. 이전 연구는 스피커에 의한 연료와 공기 혼합체 섭동에 대한 난류, 층류 예혼합 화염의 반응, 그리고 화염에 직접 축 방향 압력파를 가진하는 경우로 나뉜다. 본 연구에서는 액체로켓엔진 연소환경을 모사한 연소화염의 횡 방향 가진파에 대한 화염 응답 함수 파악을 위한 실험 장치를 고안하여 제시하였다.

Key Words: Combustion Device(연소장치), Combustion Instability(연소불안정), Perturbations(섭동), Acoustic Excitation(음향가진), Premixed(예혼합), High Frequency(고주파), Transfer Function(응답함수)

1. Introduction

Combustion instability has been a critical technical issue for the development of high-energy-density power systems, which operate at high chamber pressure and temperature. Since the nature of the phenomenon is highly complicated mainly due to its nonlinear and case-sensitive behavior, its understanding requires a systematic approach. One of key mechanisms is the interaction between heat release fluctuations and acoustic perturbations because they are coupled to keep

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providing energy for resonant acoustic waves required for being sustained in a combustion chamber. From this reason, the objective of the present study focuses on the dynamic characteristics of flame response to acoustic fluctuations. One of approaches for this purpose will be the investigation of flame response characteristics to external, i.e., artificial acoustic perturbations.

In this article, first, some of previous, prominent research works will be presented and the systematic approach of experimental research has been designed.

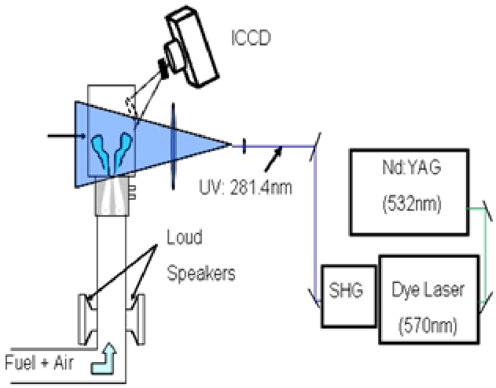

Fig. 1 Schematic for the Experimental Setup[1,2]

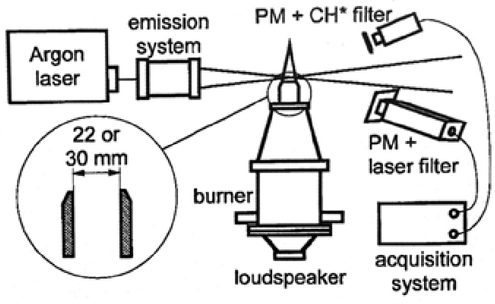

Fig. 2 Experimental Schematic for the Laminar Conical Flame Burner[3]

2. Literature Review

2.1 Turbulent Premixed Combustion of Forced Mixture

Thumuluru and Lieuwen[1,2] conducted experiments on premixed combustion flame response upon forced fresh mixture of natural gas and air. Their research motivation is the identification of controlling parameters of flame dynamics. They suggested that the parameters include annular jet fluctuations, oscillatory turbulent flame brush development, flame stabilization, and fluid mechanical instabilities of the backward facing step, jet column, swirl, and shear layer. They concluded that the determination of which parameter will be significant is fairly dependent on forcing frequency, amplitude of excitation, and flame stabilization dynamics.

2.2 Laminar Premixed Combustion of Forced Mixture

Ducruix *et al*[3]. showed experimental results acquired from the laminar premixed combustion with forced inlet mixture of methane and air. They developed laminar premixed flame response model and conducted experiments in a conical flame. They tested two types of burners with the different exit diameter burning a mixture of methane and air at an equivalence ratio of 0.95. Transfer functions between 5 and 300 Hz were determined in the study and they introduced the reduced frequency, $\omega_* = \omega R / S_L \cos\alpha_o$ for the determination of characteristics of the transfer functions.

2.3 Forced Lean Premixed Flame

For a premixed lean swirl burner, Yilmaz *et al*[4]. applied excitation acoustic waves to perturb the flame and initiate shear layer vortices. The amplitude of the excitation wave is around 0.05% of mean pressure. The swirl burner has a swirl number of 0.5 and 65 degrees of vane angle. Acoustic excitation was realized by using four 30-cm-diameter speakers powered by a power amplifier. The forcing frequencies were 85, 125, 222, and 399 Hz.

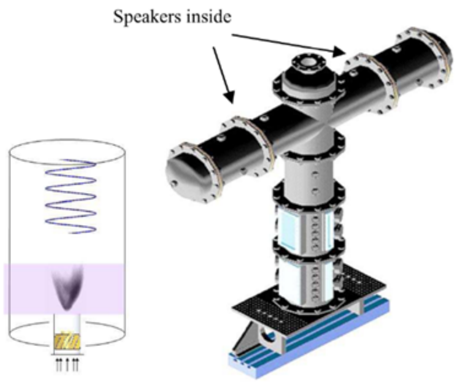

Fig. 3 Schematic of the Experimental Burner[4]

3. Literature Summary

Most of acoustic excitations were forced on the inlet flow of combustors in the previous studies. Laminar premixed or turbulent premixed flames were exposed to the excitations for the assessment of their response. For the investigation of the response, heat release rates and acoustic measurements were applied. For heat release rate measurement, chemiluminescence and OH PLIF became popular tools in most of the previous studies. Also, a few studies were known that turbulent flames were exposed to hot-product-side acoustic excitation, which basically a plane wave is travelling along the axis of the flame.

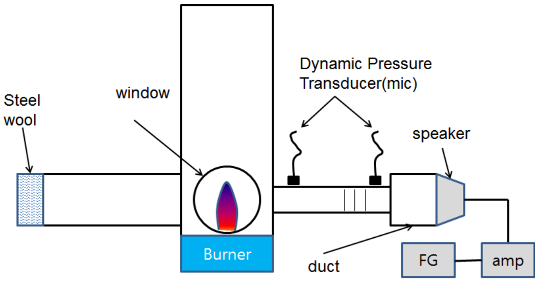

Fig. 4 Preliminary Design of the Experimental Setup for the Assessment of Flame Response to External Acoustic Perturbations

4. Preliminary Design

The main idea of an experimental setup proposed here is to assess the flame response of premixed swirling flow to the external acoustic excitation in the transverse direction. This lateral acoustic excitation can be considered a unique feature of the present study compared with the previous investigations presented above. This kind of physical phenomena may simulate the situations occurring in liquid rocket thrust chambers in which transverse acoustic resonance is often excited. The schematic is shown in Fig. 4. The burner consists of the swirling fuel nozzle and the chamber duct operating at an ambient pressure. The excitation plane wave is generated by one loud speaker installed at the end of the side duct. The speaker is powered by the power amplifier and its signal input is provided by a function generator. The other end of the pressure excitation is equipped with steel wool that is supposed to absorb the acoustic wave travelling from the loudspeaker[5].

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