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연소 조건하의 동축형 분사기의 동적 특성 고찰

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Dynamics of Coaxial Swirl Injectors in Combustion Environment

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ABSTRACT

Unielement combustion tests were conducted using coaxial bi-swirl injectors. Major experimental parameters were a recess length and a fuel-side swirl chamber. Combustion efficiency mainly depends on a mixing mechanism for the present coaxial swirl injectors. Low-frequency pressure excitations around 200Hz were observed for all injectors. However, dynamic behaviors considerably differ for an external and an internal mixing case controlled by a recess length. The internal mixing induces mixture to be biased at a specific frequency in a mass flow rate, which results in a relatively high amplitude of pressure fluctuations but results for the external mixing case show that fuel and oxidizer mixture flow carries more complicated, multiple wave characteristics due to broad mixing region as well as disintegration and merging phenomena of propellant films.

Key Words: Coaxial Swirl Injector(동축 와류형 분사기), Liquid Rocket Engine(액체 로켓 엔진), Dynamic Characteristics(동적 특성), Subscale Test(축소형 모델 시험)

INTRODUCTION

An injector is regarded as a critical component for a liquid rocket engine in that it mixes propellants and as a result, affects a combustion efficiency in various ways. Since the advent of a liquid rocket engine, various types of devices injecting liquid propellants have been devised and actually serviced in rocket engines. Among many types, three different configurations can be categorized for a liquid propellant injector; an impinging, a coaxial and a pintle injector. An impinging injector may be considered as a simplest one in terms of its operating mechanisms and difficulties of fabrication. Because of the advantages, impinging type injectors have been investigated in a great extent especially in the United States and serviced in a huge thrust chamber like F-1[1]. Nonetheless, very

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occasionally, the simplicity of an impinging injector was plagued by its natural susceptibility to combustion instability. Coaxial injectors have been widely used also in many countries. Russia may be considered as a leading nation in trying to get the best out of this type of an injector. Most of Russian liquid rockets serviced so far employ a coaxial injector. Due to its good propellant mixing characteristics and inherent resistance to combustion instability, swirl type coaxial injectors have been used in a rocket engine fed by bi-liquid propellants[2]. A pintle injector with an advantage in throttling operation often has been considered in a special engine like TRW's LCPE. In this paper, experimental data from unielement combustion of various coaxial swirl injectors will be investigated focusing on their dynamic characteristics. Since a swirl chamber in a coaxial injector forms space for sustaining surface waves, dynamic characteristics of a coaxial injector becomes unique compared to an impinging injector. Moreover, the mixing characteristics resulting in a change of combustion efficiency are expected to be affected by a recess length as well as a swirl chamber. A recess length also determines whether two propellants meets each other inside of an injector or not.

Even though coaxial bi-swirl injectors have been in a favour of Russians for their bi-liquid propellant rocket engines, experimental data and results for effects of design parameters on combustion and dynamic characteristics, available on public domain, are very scarce[2,3,4]. Therefore, the present study definitely becomes one of few available results discussing the issue.

Table 1. Specifications of coaxial bi-swirl injectors

Category		A	B
Fuel Swirl Chamber		Yes	No
Recess Number (length in mm)	1	0.6(1.9)	0.6(1.9)
	2	1.0(3.2)	1.0(3.2)
	3	1.5(4.8)	1.5(4.8)
	4	2.0(6.4)	2.0(6.4)

EXPERIMENTS

The description of the test facility and other experimental devices used in this study were described in detail in authors' previous literature[5]. Eight different coaxial injectors have been combustion tested as listed in Table 1. The major category discerning the injectors is whether it has a swirl chamber in fuel side or not and each category has four different recess length designs. For the identification of dynamic characteristics, pressure fluctuations were measured using dynamic pressure sensors (PCB piezoelectrics) for both manifolds and a combustion chamber, and recorded at a sampling rate of 50kHz.

RESULTS AND DISCUSSIONS

A Combustion test for each injector usually lasted for three seconds at a fixed thrust condition with a chamber pressure of about 52bar. Combustion efficiencies assessed by characteristic velocity data are presented in Fig. 1. Propellant mixture burns more efficiently as a recess length increases, which indicates an increase of mixing time of two propellants flowing into a main combustion zone in the combustion chamber. For internal mixing cases ($RN \geq 1$), a combustion efficiency seems not to be affected by a change of dynamic characteristics in fuel flow in the

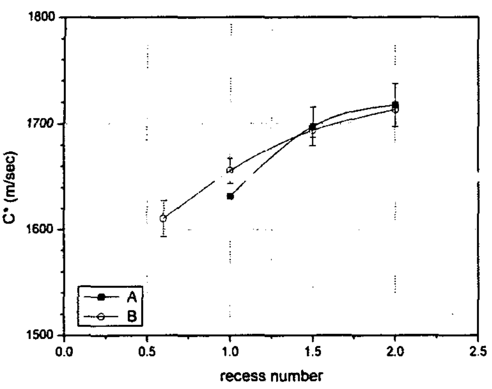


Figure 1. Characteristic velocities as a function of a recess number

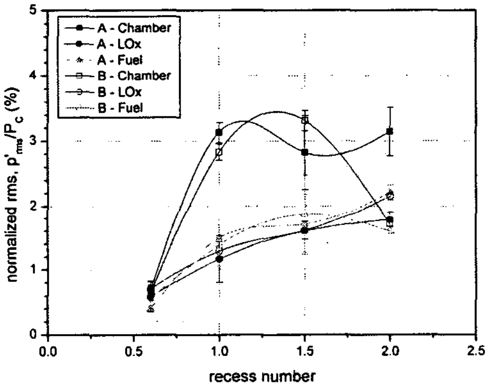


Figure 2. Normalized pressure fluctuations as a function of a recess number at each measurement location.

vicinity of a swirl chamber. The results signify that a combustion efficiency of swirl injectors are dominantly influenced by mixing rather than a droplet size[6].

Intensities of dynamic pressure fluctuations indicated by root-mean-square values are plotted in Fig. 2. Degrees of chamber pressure normalized values can be demarcated by whether incipient mixing region occurs inside of an injector or not. For internal mixing cases, (RN≥1), a RMS intensity is approximately three percents of chamber pressures regardless of a fuel-side swirl chamber and a recess length. Pressure fluctuation intensities in manifolds are in a very similar order to each other and intensities in a chamber for external mixing cases are reduced to comparable values with those in manifolds. Two major excitation sources can be regarded in this case for sustaining pressure fluctuations in manifolds and a chamber. One is combustion and the other flow separation from cavitating venturies in supply lines.

Frequencies of the most energetic pressure fluctuations measured at each location can be identified using a FFT analysis and presented in Fig. 3. Pressure wave frequencies sustained in manifolds and a chamber range between 100 and 250Hz. One thing clear from this plot is that pressure waves between manifolds and a chamber are losing their coherence as a recess length decreases, and for the external mixing case, number of pressure waves with comparable power do exist as can be observed

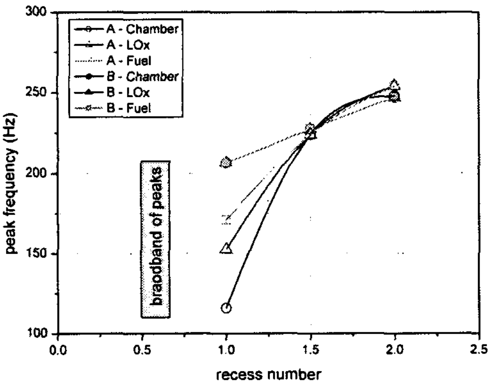


Figure 3. Frequencies of the most energetic pressure fluctuations identified using a FFT analysis.

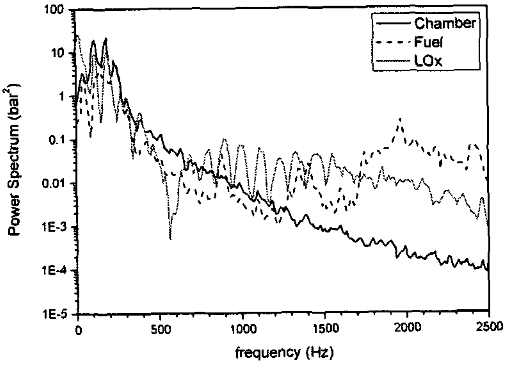


Figure 4. Power spectrum plots for dynamic pressure measurements at a test of a B-1 injector.

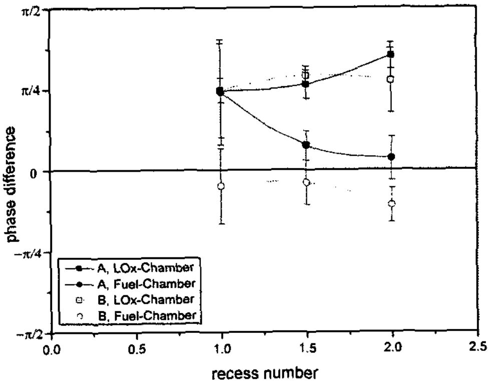


Figure 5. Phase differences between each measurement location depending on a recess number.

in Fig. 4. From these results, it is obvious that main energy source for sustaining pressure waves in manifolds is combustion and pressure waves are more closely associated with each other across an injector as first mixing region resides at the more inside of an injector.

For the internal mixing cases with definite peak frequencies, phase differences between pressure waves having the same frequency can be estimated using a response function as plotted in Fig. 5. A phase difference between a LOx manifold and a combustion chamber seems to stay at a constant value, ~π/4, regardless of a recess length and it is interesting to observe that for the case with a fuel-side swirl chamber, a pressure difference abruptly increases from around zero to π/4 as incipient mixing region approaches fuel nozzle tip.

Amplitude/phase diagram of a response function of a flow rate to a dynamic pressure difference across an injector is plotted in Fig. 6 using the swirl injector theory suggested in [7], which is drawn for the configurations of LOx side of the present injector. A response of a LOx flow rate becomes the highest at a pressure perturbation frequency of about 520Hz although experimental data reveals their peaks around 250Hz where a dynamic pressure difference across an injector is predicted to be in phase with flow rate fluctuations. The theory only predicts hydraulic phenomena occurring in the LOx side with a swirl

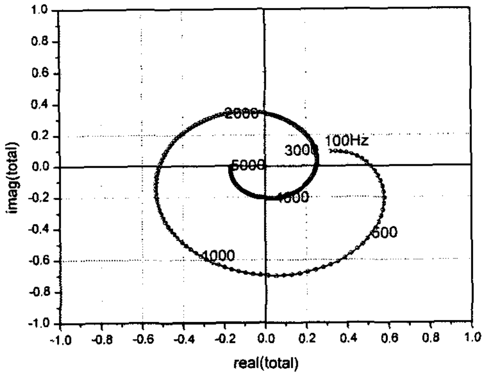
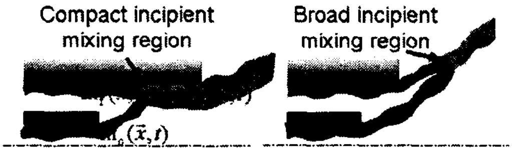


Figure 6. Amplitude/phase diagram of a response function for the LOx side of the coaxial injectors adopted from ref. [7]

chamber and it needs ~~to be~~ further ~~developed~~ into one that couples phenomena in fuel side, mixing and combustion.

Upon the results discussed so far, the following explanation can be presented being assisted by the sketches in Fig. 7. For an internal mixing case, fuel and oxidizer meets and mixes inside of the injector, and variations of mixture in a total flow rate and O/F ratio become dependent only on fuel and oxidizer mass flow rates that have definite characteristic frequencies. Thus, a heat release rate from subsequent combustion results in a monotone. However, for an external mixing case, fuel and oxidizer mixes over broad region compared to an internal case and so resultant mixture turns out to have a more disperse spatial distribution of O/F ratio. Also, propellant films being unbounded by solid wall can carries multiple wave characteristics. Even first incipient mixing region is exposed to pressure fluctuations inherent or induced in a combustion chamber. As a result from an energy transfer between heat release and pressure waves, pressure fluctuations in a chamber reveal multiple peaks not coupled to a specific frequency as shown in Fig. 4.



(a) (b)

Figure 7. Artist's sketch of propellant film mixing occurring for (a) an internal mixing case and (b) an external mixing case

CONCLUSIONS

Experimental data concerning dynamic behavior of various coaxial swirl injectors have been analyzed and their results were discussed. A combustion efficiency heavily depends on mixing for a coaxial swirl injector. It is concluded that dynamic behaviors considerably differ for an external and an internal mixing case controlled by a recess length. Mixture formed in the inside of an injector has specific frequency characteristics in O/F ratio mainly determined by fuel and oxidizer mass flow rates at a mixing region. This leads to a relatively high amplitude in a combustion chamber dynamic pressure. However, for the external mixing case, fuel and oxidizer mass flow rates carry multiple wave characteristics due to broad mixing region as well as disintegration and merging phenomena of injected propellant films.

ACKNOWLEDGEMENTS

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