공학석사학위논문

A Study on Dynamic Characteristics of Gas Centered Swirl Coaxial Injector with Acoustic Excitation

기체 중심 스월 동축형 인젝터의 기체 가진 동특성 연구

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이 정 호

Abstract

A Study on Dynamic Characteristics of Gas Centered Swirl Coaxial Injector with Acoustic Excitation

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Combustion instability is critical problem in developing liquid rocket engine which is the phenomenon occurred by the combination of combustion in its chamber and the flow of propellants supply system. The combustion instability phenomenon basically aggravates the combustion efficiency and control system, and moreover it can triggers the destruction of engines in severe cases. The several methods like baffle and cavity have been used for suppression of combustion instability.

In this study, the method as part of these efforts to suppress combustion instability was sought through the injector. One cause of the combustion instability is the disturbance of feeding propellants and such disturbance can be generated for various reasons. Because the disturbance can be amplified which is propagated to the combustion chamber and its effect undergoes feedback process returned to the supply system, the design of the injector in the middle of such a chain process is very important. If the injector can suppress the disturbance coming from the supply line as a kind of buffer it will serve to reduce combustion instability. However, previous research was mainly only about the response of disturbance in a single swirl injector with liquid pulsation. The research about the response of disturbance in gas-liquid injector with acoustic excitation has not been conducted much.

In this study, the response characteristic was observe by acoustic excitation of speaker to simulate the phenomenon that gas propellant is supplied with disturbance in gas centered swirl coaxial injector. The film thickness at injector exit which affects various spray characteristics such as spray angle, break up length, SMD was measured by using a liquid film electrode. Also the response of spray to the disturbance was observed by high-speed photography. The recess ratio, the gap thickness, the gas-liquid momentum flux ratio, the frequency of feeding gas was changed to investigate the effect of these experimental parameters.

Keywords: Liquid Rocket Engine, Gas Centered Swirl Coaxial Injector, Combustion instability, Dynamics, Acoustic Excitation, Recess Ratio.

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Chapter 1 INTRODUCTION

1.1 Combustion instability

The combustion instability, one of the hot issue in liquid rocket engines, is the phenomenon occurred by the combination of combustion in chamber and the flow of propellants supply system. The combustion instability phenomenon basically aggravates the combustion efficiency and control system, and moreover it can triggers the destruction of engines in severe cases. The several methods like baffle and cavity have been used for suppression of combustion instability [1]. Fig. 1.1 shows the mechanism of combustion instability.

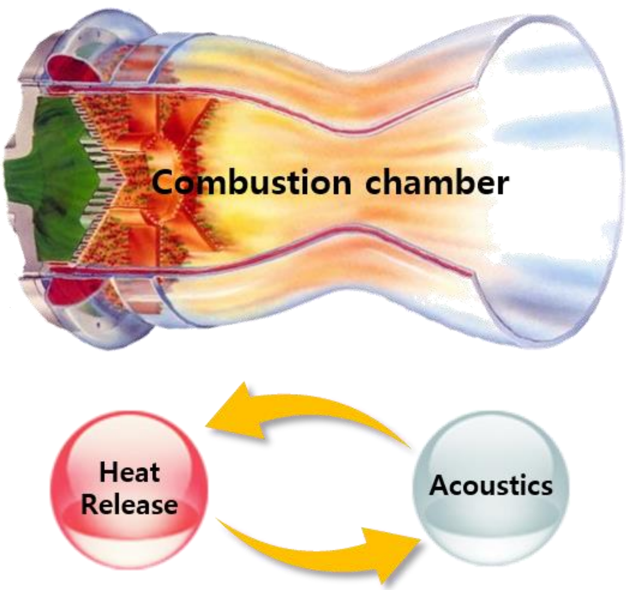

Figure 1.1 Mechanism of combustion instability.

Rocket engine combustion instability can be classified according to its frequency. Table 1.1 shows three types of rocket engine combustion instability. The mechanism of low frequency combustion instability and intermediate frequency combustion instability is associated with coupling of the combustion chamber and the feed system. Though the mechanism of high frequency combustion instability is not completely connected to feed system, the fluctuation of feeding propellants can trigger this type of instability [2]. So the perturbation of feeding propellant is significant part of combustion instability problem.

Type	**Name**	**Range**	**Mechanism**
Low frequency	chugging	~ 200 Hz	Coupling of the combustion chamber with the feed system
Intermediate frequency	buzzing	200~1000 Hz	Coupling of the combustion chamber wave with the feed system
High frequency	screaming	1000 Hz ~	The acoustic instability or resonant combustion

Table 1.1 Types of combustion instability.

1.2 Dynamic characteristics of injector

The mass perturbation of propellants is crucial cause of occurring the combustion instability. The propellants supplied into the combustion chamber could have the perturbation of flow by the various source such as; the pressure perturbation by combustion in pre-burner, mass flow perturbation by turbine or pump, the pressure perturbation by the geometry of supply line. Besides the mass flow perturbation can be generated from supply system under the influence of pressure perturbation at injector exit in other words combustion chamber.

Fig. 1.2 shows the process that each part propagates disturbance. If perturbations from the supply system were not reduced enough, the pressure perturbation in the combustion chamber would increase and the feedback would repeat again. Therefore, the design of the injector is very important which is in the middle of the serial process. If the injector is designed optimally to work as a part of a buffer and suppress the perturbation coming from supply line, the spray instability which leads to combustion instability will be prevented.

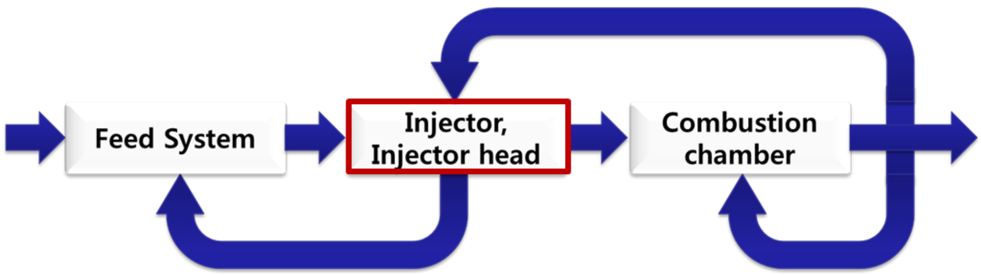

Figure 1.2 Process of disturbance propagation.

Bazarov et al. displayed the propagation of perturbation occurred between combustion chamber and supply system in diagram form and conducted the experimental test about the injector dynamics and self-pulsation to solve these phenomenon. Characteristics of single injector were observed with experiments using pulsator and the transfer function between the pressure and the mass flow rate for jet and swirl injector was derived from wide frequency range [3]. Ismailov et al. proposed various models of self-resonance in close-type single swirl injector when disturbance exists and analyzed it numerically [4]. Kill et al. studied the characteristics of dynamic response of liquid film according to liquid supply perturbation in the single swirl injectors [5].

1.3 Previous studies of gas centered swirl coaxial injector

The gas-centered swirl coaxial injector which was used in this study has been employed in staged combustion cycle liquid rocket engine in Russia and it has been conducted since 1990s. Muss et al. suggested the injector design method through the characteristics of spray and combustion in gas-centered swirl coaxial injector [6]. Schumaker et al. studied the spray characteristic by capturing the internal flow according to the injector geometry and the momentum flux ratio [7]. Im et al. compared the spray characteristics of the gas-centered swirl coaxial injector and the liquid-centered swirl coaxial injector [8]. Matas et al. used Laser Induced Fluorescence method by capturing the internal flow and figured out how similar internal flow works in same momentum flux ratio and measured the liquid film frequency [9]. Fig. 1.3 shows LIF method image gained by Matas et al.

However, the previous dynamic experiments were conducted by the responses made from single swirl injector about characteristic of liquid perturbation. The study about gas perturbation in gas-liquid coaxial injector almost has not been conducted. In this study, the spray characteristics with acoustic excitation in other words feeding gas perturbation were measured in the gas-centered swirl coaxial injector.

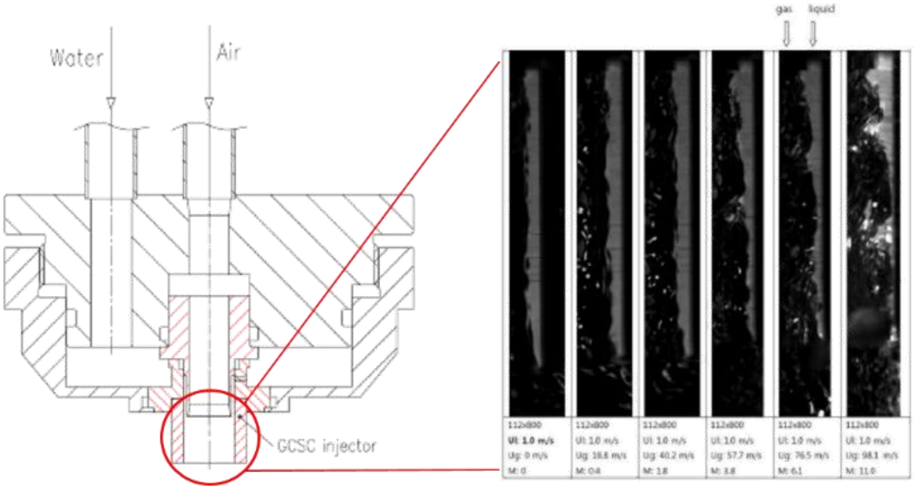

Figure 1.3 Visualization of recess area with LIF method by Matas et al. [9].

Chapter 2 APPARATUS AND EXPERIMENTAL METHOD

2.1 Gas centered swirl coaxial injector

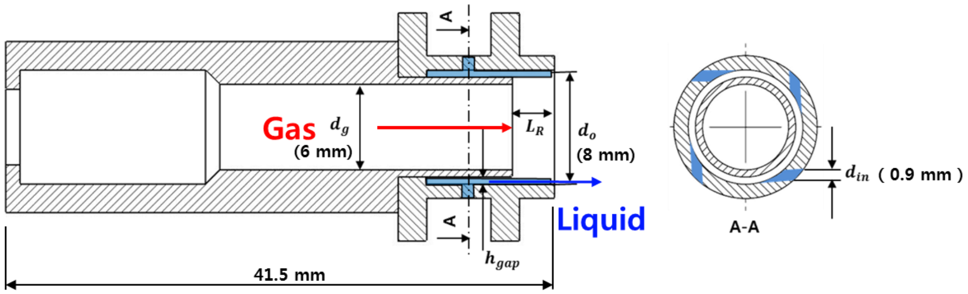

Figure 2.1 Gas centered swirl coaxial injector.

Figure 2.1 shows specific structure of gas-centered swirl coaxial injector used in experiment. Gas is injected in a form of jet along the central axis. Liquid is injected through tangential entry (d_{in}) which diameter is 0.9 mm and flows along the outer wall of gas orifice with the form of swirl. The inner diameter of gas orifice (d_g) is 6 mm and that of liquid orifice (d_o) is 8 mm. The space between both orifice is decided by the thickness of gas orifice wall, in other name, lip thickness, and that space which is called as gap thickness (h). The length from the end of gas orifice to that of liquid orifice is called recess length (L_R). Total length of the gas centered swirl coaxial injector is 41.5 mm.

2.2 Experimental Apparatus

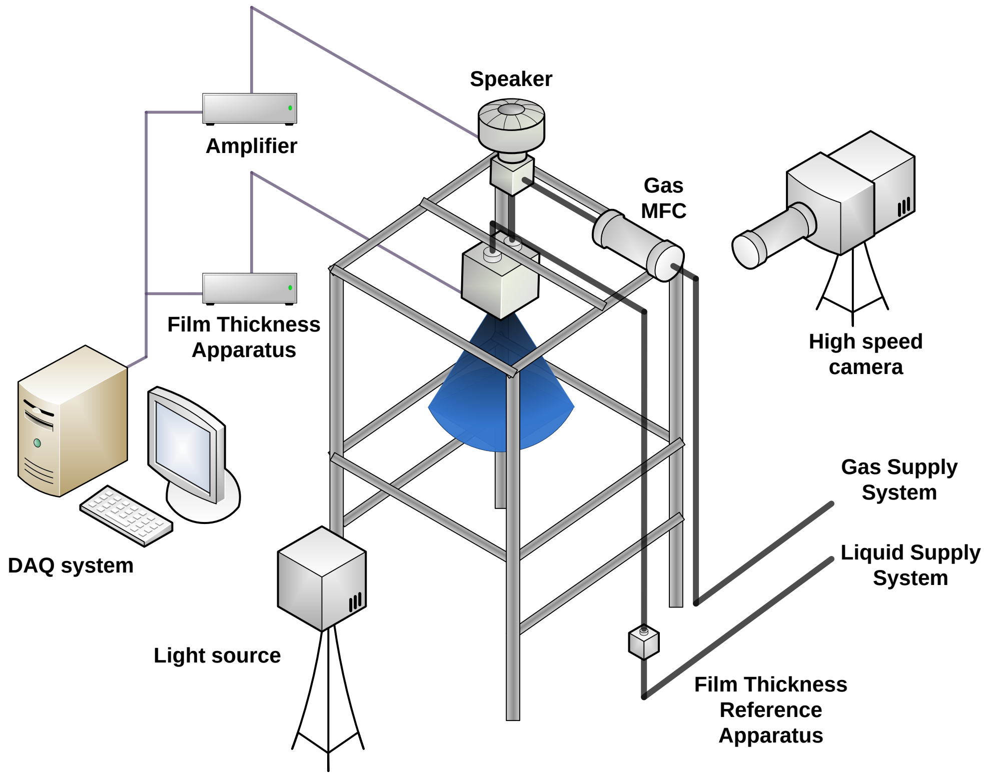

Figure 2.2 Experimental Apparatus.

Figure 2.2 shows experimental apparatus. The gas centered swirl coaxial injector was installed at test rig. Water and air were used as experimental fluid to substitute for liquid kerosene and oxidizer rich gas respectively. Water was supplied from high pressure water tank to maintain constant supply pressure. Mass flow rate of water was measured at various pressure drop between injector manifold and atmosphere in advance and gained by converting measured pressure with conversion formula in all experiment. Fig. 2.3 shows water mass flow rate along pressure drop. Mass flow rate of air is controlled by mass flowrate controller (Line Tec; MFC M3500V).

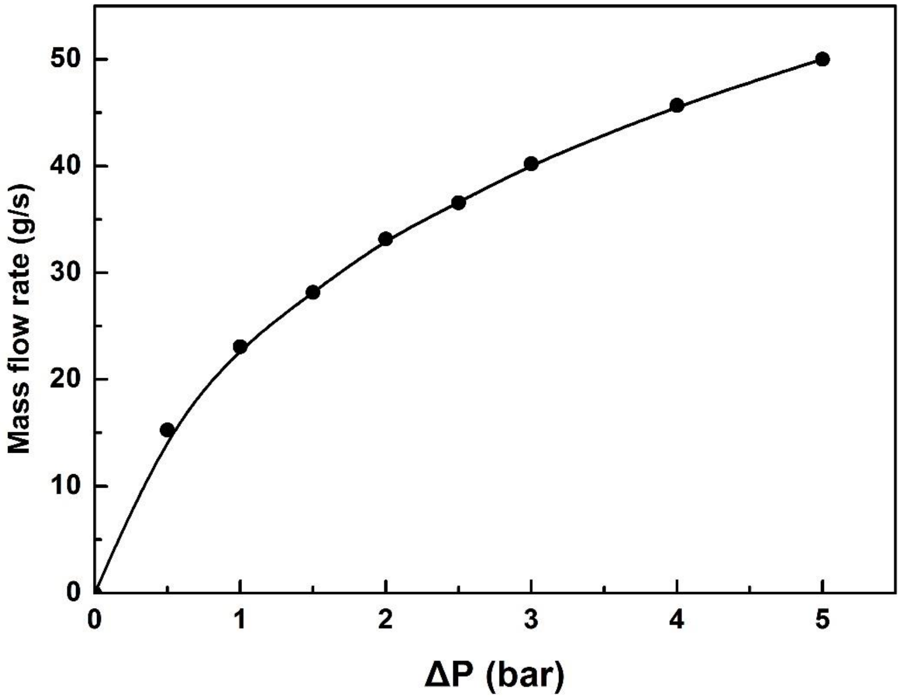

Figure 2.3 Mass flow rate of water versus pressure drop.

2.3 Acoustic Excitation

In order to generate acoustic excitation of proper amplitude and frequency, speaker is used. Fig. 2.4 shows the schematic diagram of Acoustic Excitation Apparatus. The speaker (SAMMI SU-150EF) was installed in the middle of gas supply line before injector. The input signal was set by frequency and voltage in DAQ (NI Instrument) system and amplified in the amplifier (BOSTONAUDIO CC-350). The gas velocity perturbation before injector was measured by the hot wire anemometry (Dantec

Dynamix Mini CTA model).

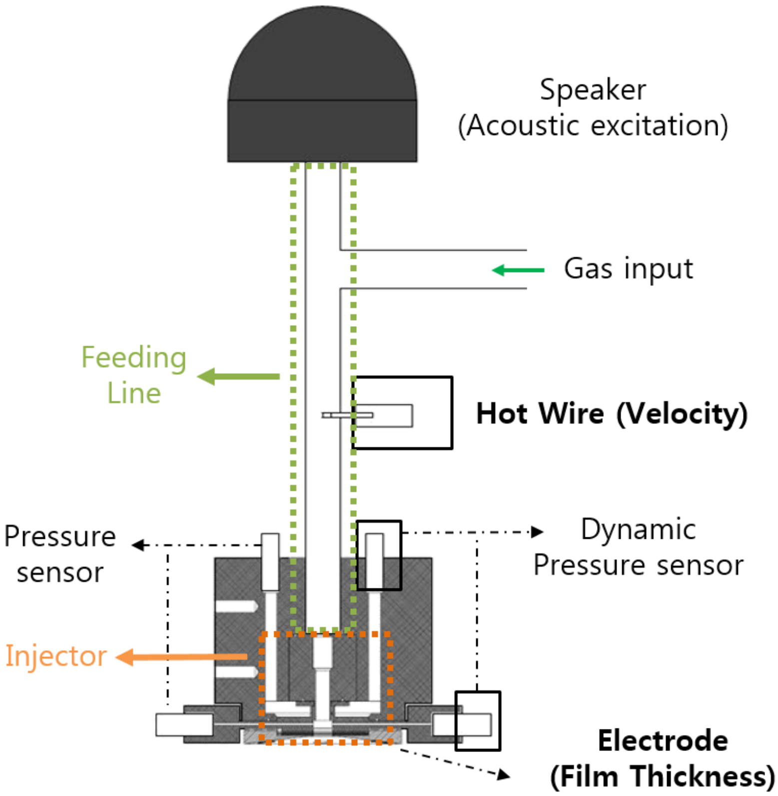

Figure 2.4 Schematic diagram of Acoustic Excitation Apparatus.

2.4 High speed photography

To observe the behavior of spray and measure spray sheet oscillation frequency, high speed photography was used. High speed camera (Photron FASTCAM-ultima APX) is installed in front of test rig and continuous light source (Photron HVGSL) is installed at the back of test rid. The high speed images were gained with the frame rate of 10000fps and resolution of 512 X 256.

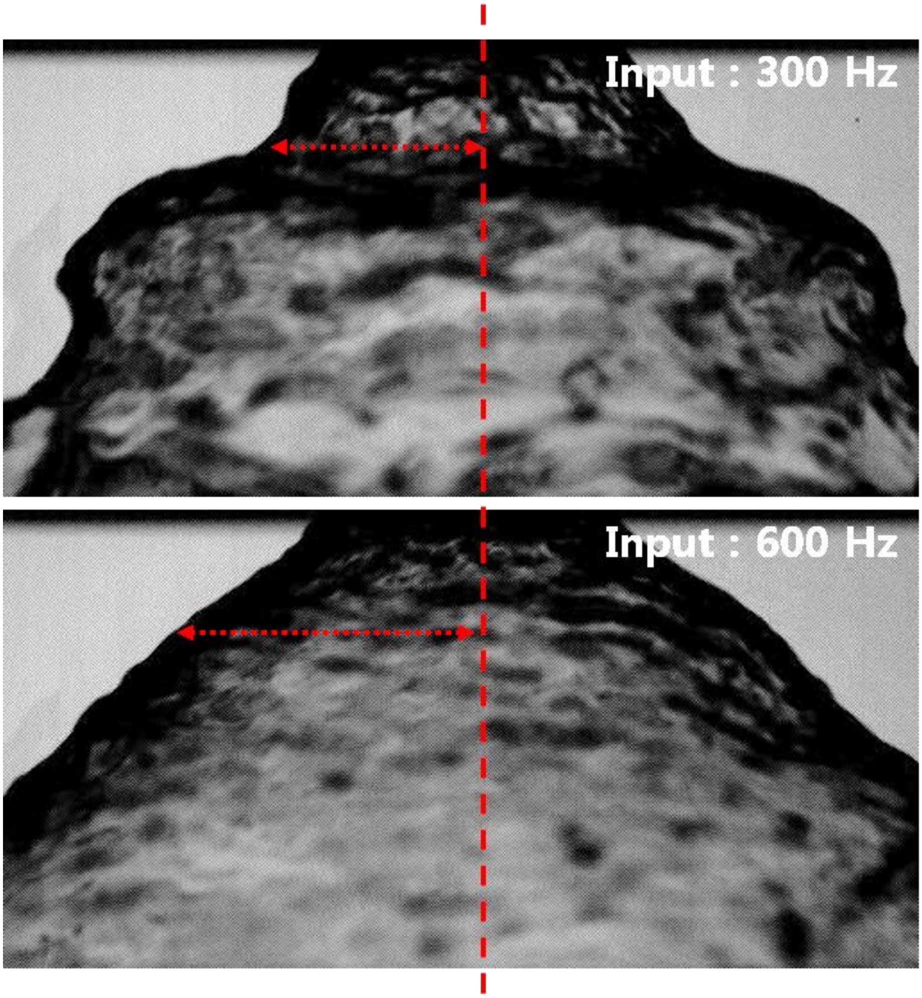

Figure 2.5 Measurement of spray sheet oscillation.

Figure 2.5 shows how to measure the spray sheet oscillation. At the point which is half of orifice diameter far from injector end the edge of spray is measured by post processing of high speed images. Matlab is used for post processing of the images.

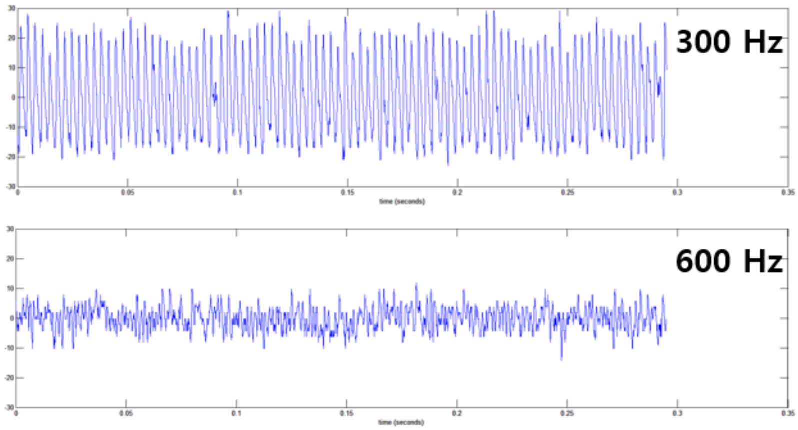

Figure 2.6 Time versus spray sheet movement.

Fig. 2.6 shows the graph of time versus spray sheet movement. In this graph it is confirmed that the magnitude of fluctuation in 300 Hz and that in 600 Hz is different. After transferring the data by Fast Fourier Transform (FFT) process, the oscillation frequency and amplitude of spray sheet are gained. Fig. 2.7 shows the result. This result more clearly shows the difference of magnitude between two cases.

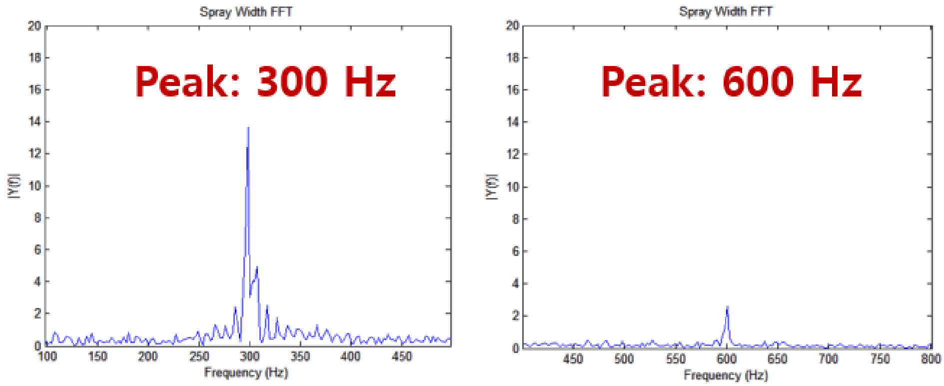

Figure 2.7 FFT result of spray sheet oscillation.

2.5 Liquid film measurement

The electrode method which was suggested by Lefebvre et al. was used for measuring the variation of liquid film [10]. This method is to use the electrical conductivity of water. The voltage of circuit changes with the liquid film thickness. Fig. 2.8 show the structure of electrode used for measuring liquid film thickness of injector exit. Two thin electrodes were installed with isolation material between them at the injector exit. The acrylic rods of different size were used to make specific thickness of liquid film artificially and then the calibration curve of voltage and liquid film was gained [11]. Fig. 2.9 shows the calibration curve used in experiment.

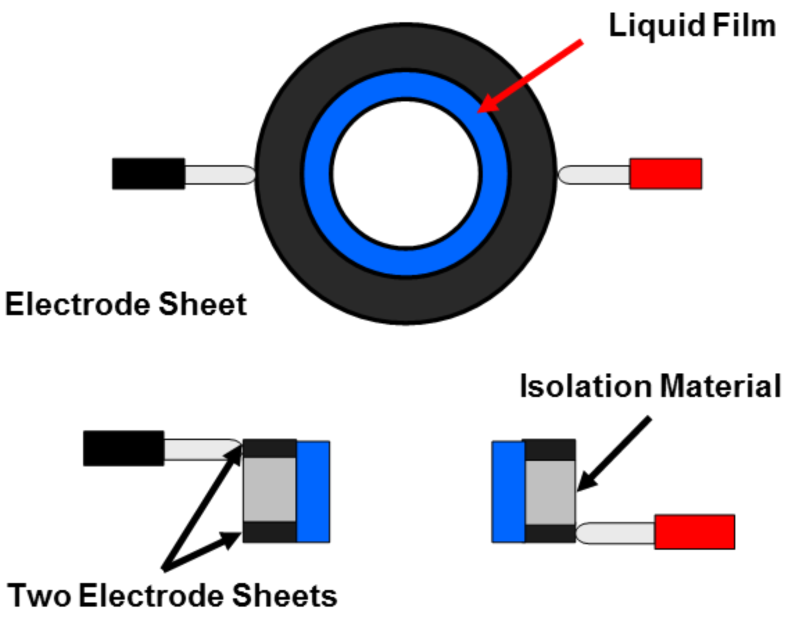

Figure 2.8 Electrode for measurement of liquid film thickness.

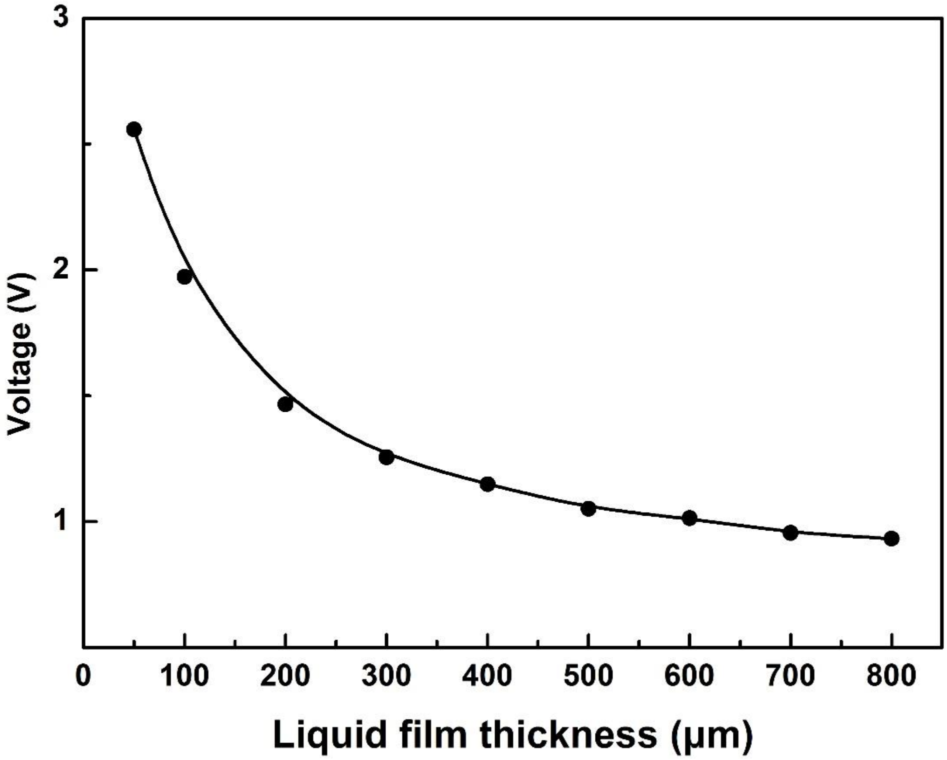

Figure 2.9 Calibration curve of voltage and liquid film thickness.

2.6 Experimental condition

The disturbance of feeding propellants can be several hertz to several thousand hertz depending on the cause of occurrence [2]. In this study, excitation frequency was changed 200 Hz to 1100 Hz with interval of 100 Hz for reflecting various cause of occurrence. Recess ratio, space where gas and liquid are mixed, is defined in Eq. 2.1 as the ratio of recess length and inner diameter of gas orifice. Recess ratio was changed 1 to 3 with unit 1. As another injector geometry parameter, gap thickness was changed. The experiment was made by switching it into 0.3, 0.5 and 0.7. Also, the momentum flux ratio which is used as major variables in coaxial injector was change 0.5, 1, 1.5, 2 and it is defined in Eq. 2.2 where U_g is gas velocity and U_{la} is axial liquid velocity. Table 2.1 shows experimental conditions.

$$RR = \frac{L_R}{d_g} \tag{2.1}$$

$$MR = \frac{\rho_g U_g^2}{\rho_l U_{la}^2} \tag{2.2}$$

Phase	Gas	Liquid
Fluid	Air	Water
Velocity (m/s)	26.35 ~ 97.24	1.28 ~ 2.82
Mass flow rate (g/s)	0.9 ~3.33	15.26 ~ 33.16
Frequency of excitation (Hz)	200 ~ 1100	
Momentum flux ratio	0.5, 1, 1.5, 2	
Recess ratio	1, 2, 3	
Gap thickness (mm)	0.3, 0.5, 0.7	

Table 2.1 Experimental conditions.

Chapter 3 RESULTS AND DISCUSSION

3.1 Meaning of Gain

Liquid film thickness at injector exit is significant parameter which effects spray characteristics such as spray angle, break up length, SMD [12]. So it is very important to understand the liquid film variation when there is disturbance of gas phase feeding propellant in the light of spray instability and combustion instability.

In this study, the main topic is how response is changed as variation of many parameters. To compare results of various conditions, data was analyzed with following values. Input value is defined as Eq. 2.1 which means the velocity fluctuation of feeding gas and it is normalized by mean velocity of feeding gas. Output value is defined as Eq.2.2 which means the thickness fluctuation of liquid film at injector exit and it is normalized by mean thickness of liquid film.

$$Input = \frac{u'}{\overline{U}} \tag{3.1}$$

$$Output = \frac{t'}{\overline{T}} \tag{3.2}$$

It is obvious that response of film thickness becomes violent as the amplitude of gas fluctuation increases but increasing ratio of input and output is not sure. The experiment of varying gas fluctuation was performed to find the relation of Input and

Output. Fig. 3.1 shows the variation of input value as excitation power of speaker increases. Circle symbol is the case that gas-liquid momentum flux ratio is 2 and square symbol is the case that gas-liquid momentum flux ratio is 0.5. Straight line case is when the input value is about 0.1 and dash dot case is when input value is changed arbitrarily.

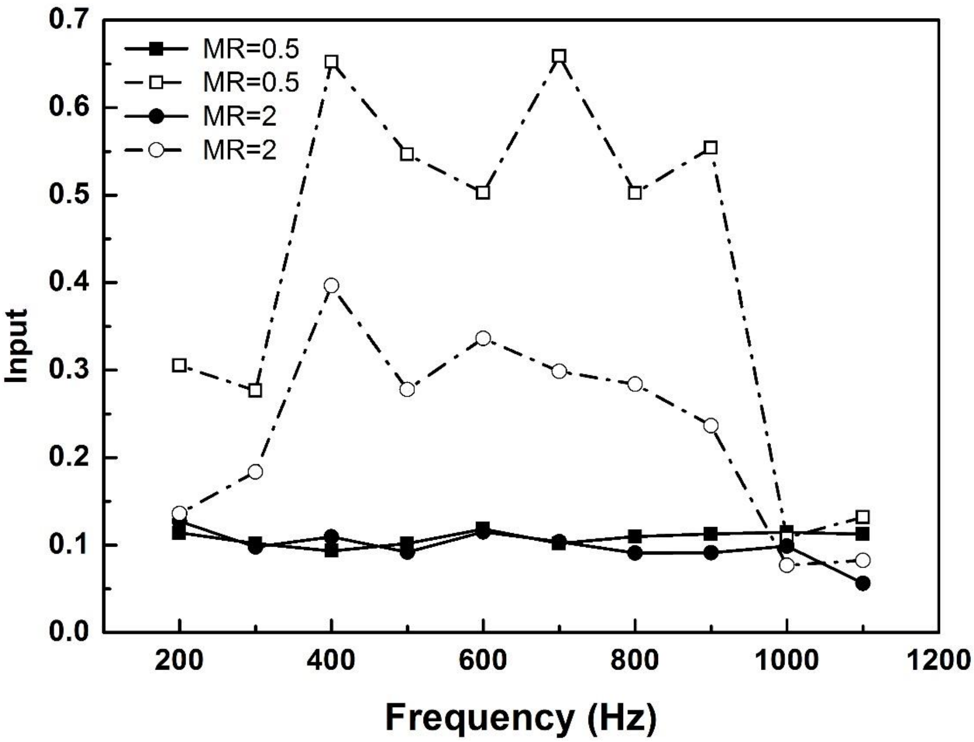

Figure 3.1 Change of excitation power (MR=0.5, 2).

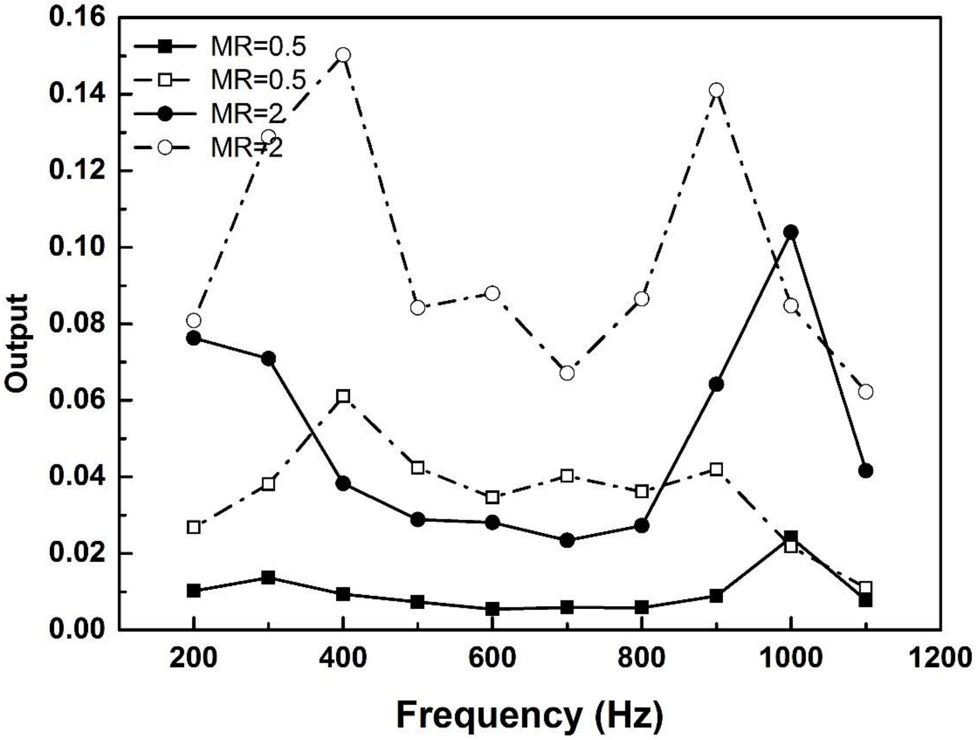

Figure 3.2 Change of Output (MR=0.5, 2).

Figure 3.2 shows the variation of output value correspond to fig. 3.1. When there is different power of acoustic excitation, which means different input value, output value is changed as similar trend with input value. Thus gain is defined as Eq. 3.3 to exclude the effect of input power.

$$Gain = \frac{Output}{Input} = \frac{t'/\overline{T}}{u'/\overline{U}} \tag{3.3}$$

Figure 3.3 is the gain graph with varying excitation power at two case. Though the excitation power has big difference, gain value is almost same at each case. In other words output value is proportional to input value and gain is proper parameter to show only the influence of variables which we want to know exclude the effect of excitation power.

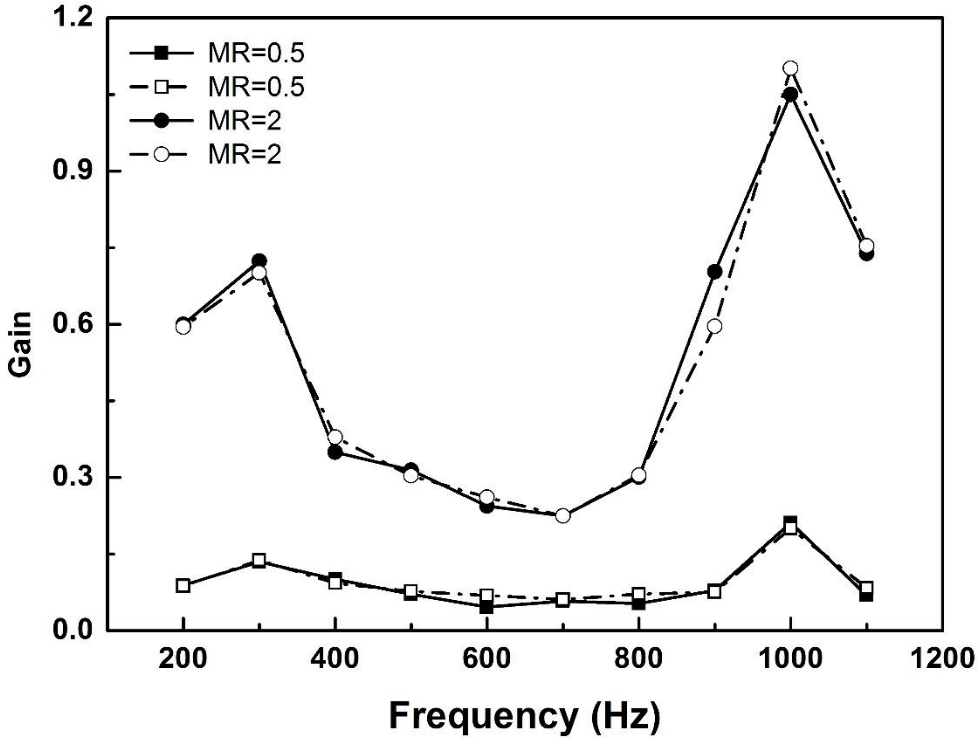

Figure 3.3 Gain of different excitation power (MR=0.5, 2).

3.2 Effect of frequency

Figure 3.4 shows the effect of disturbance frequency of feeding gas. Gain means the response of liquid film fluctuation at injector exit. There are two points the response was larger than others. Gain of 300 Hz was about three times and that of 1000Hz was about four times bigger than lower points. As it mentioned earlier, gain represent response of liquid film. So higher gain means that spray is more unstable at that frequency. As we can see at fig. 3.5 the spray was very unstable at frequency of 300 Hz and 1000 Hz which point was high gain while spray of 600 Hz was stable like no excitation case. These results imply that the frequency of high gain point can easily lead to spray instability which is related to combustion instability. If disturbance of these frequency occurred at the upper side of injector this can trigger combustion instability.

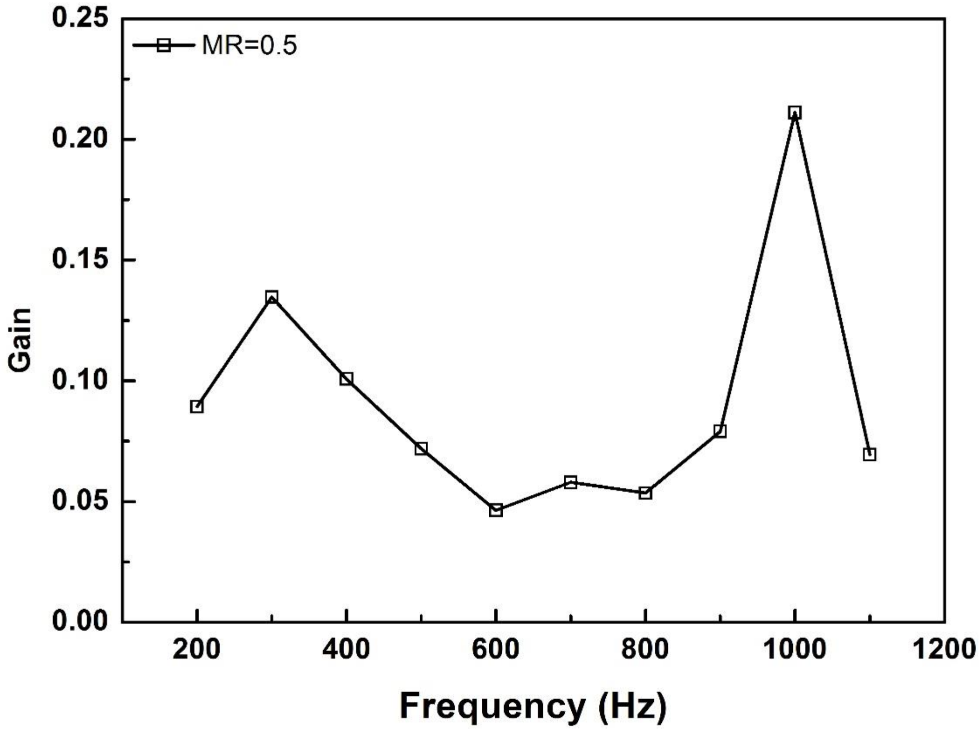

Figure 3.4 Gain of various frequency.

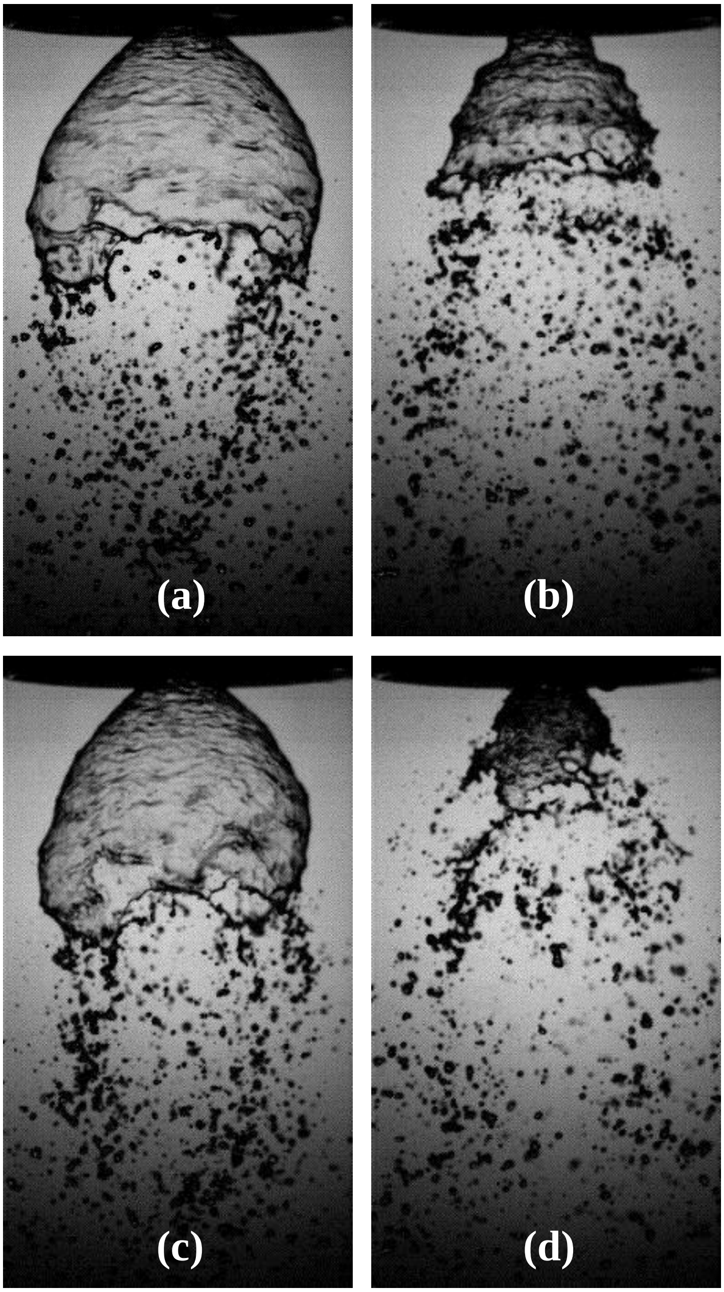

Figure 3.5 Spray image of various frequency.

(a) no excitation, (b) 300 Hz, (c) 600 Hz, (d) 1000 Hz

3.3 Cause of peak points

As mentioned above, two peak point which have high gain were found with varying disturbance frequency and that were about 300Hz and 1000Hz. Additional experiment was performed to clarify the reason of peak point. It is decided that each peak point has different cause to occur.

3.3.1 High frequency peak point

From the fig. 3.4, the frequency of large gain value at high frequency range is about 1000 Hz. This high range peak point occurs because of the feeding line. The length from speaker to injector upper side, L in fig 3.6, was confirmed as main cause of high frequency peak. This length line seemed to act as acoustic resonance tube and the disturbance of feeding gas to be amplified in this section. In case of changing line length peak point was moved to another frequency. In fig. 3.7 circle symbol is original case of frequency-gain experiment and the peak is 1000 Hz. Square symbol is the case that line is changed to shorter and the peak point was moved to about 1400 Hz. Triangle symbol is the case that line is changed to longer and the peak point was moved to about 760Hz and 1300 Hz. So it seems reasonable to judge that the length of feeding line is the cause of high peak point.

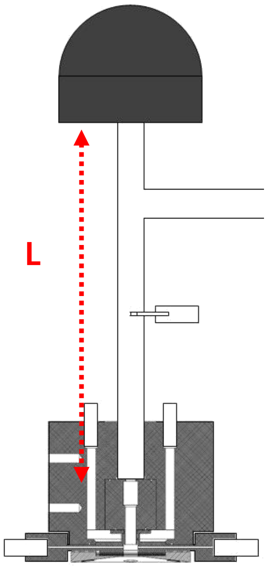

Figure 3.6 Feeding line length.

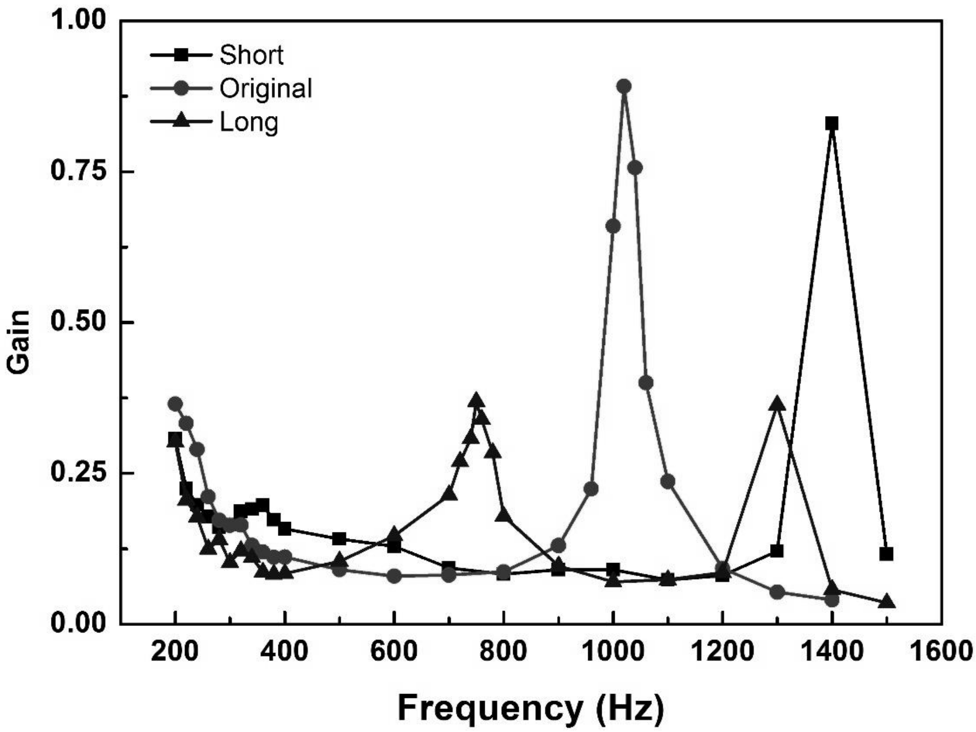

Figure 3.7 High peak movement according to line length.

$$f = \frac{c(2n-1)}{4L} \tag{3.4}$$

To ensure this judgement, resonance equation is used. Eq. 2.4 is resonance equation of close-open boundary tube. In this study, one side of boundary is speaker and the other side is the end of tube which is entrance of injector. So close-open boundary equation is applied. In this equation, L means the length of resonance tube which is represented in Fig. 3.6 as L and c is sound velocity which is used as literature value. N means the mode of resonance. The calculation result of this equation are shown in table 3.1.

Line length change				
C(m/s)	L	1^{st} (Hz)	2^{nd} (Hz)	3^{rd} (Hz)
340	0.182	467	1401	2335
	0.242	351	1054	1756
	0.332	256	768	1280

Table 3.1 Frequency calculated by Eq. 3.4.

The peak point frequency of original length tube, 1000 HZ, corresponded with second harmonic resonance frequency of Table 3.1, 1054 Hz. The peak point frequency of short length tube, 1400 Hz, corresponded to second harmonic resonance frequency of Table 3.1, 1401 Hz. The peak point frequency of long length tube, 760 Hz and 1300 Hz, corresponded to second and third harmonic resonance frequency of Table 2.1, 768 Hz and 1280 Hz. This gas tube can be corresponded to the gas manifold or feeding line. So this result imply that the design of gas feeding system is significant in the issue of dynamic characteristic of injector

3.3.2 Low frequency peak point

From the fig. 3.4 the frequency of large gain value at low frequency range is about 300 Hz. This low range peak point occurs because of different reason with high frequency peak. When the length from speaker to injector upper side, L in fig 3.6, was changed the low frequency peak didn’t move to other frequency. As we can see in fig. 3.7, the low frequency peak were almost same regardless of line length. So it is predicted that other reason cause this low range peak.

This low range peak is considered to begin from the characteristic of gas centered swirl coaxial injector. When water and air encounter at the end of gas orifice spontaneous oscillation occurs depending on the velocity difference between gas and liquid. This interfacial instability is related to viscous shear instability which occurs when there is viscosity difference across the interface of two fluid [9]. Fig. 3.8 shows the schematic of interfacial instability.

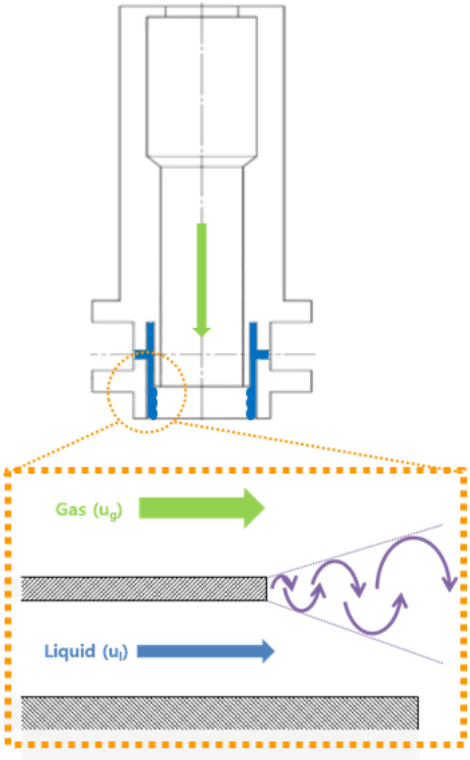

Figure 3.8 Schematic of interfacial instability.

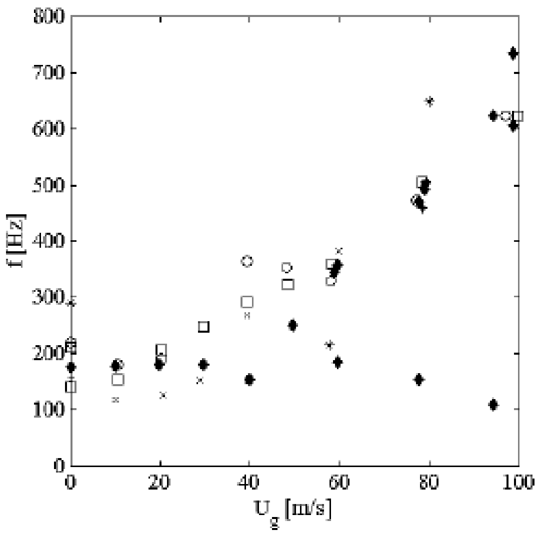

Figure 3.9 Interfacial instability from Matas et al. [9].

At Matas's experiment the internal flow of recess region in gas centered swirl coaxial injector was observed by LIF method. Fig. 3.9 shows the interfacial instability result at various condition. This graph shows the trend that instability frequency increases belong to gas velocity which means growing of velocity difference between two fluids. Fig. 3.7 is the case of low momentum flux ratio case which is 1 and fig. 3.10 is the case of high momentum flux ratio case which is 2. The gas velocity of MR=1 case is about 50 m/s and that of MR=2 case is about 80 m/s. From fig. 3.7 and fig. 3.10 the low frequency peak appears as about 200 Hz and 300 Hz. It is not exactly same with the result of Matas et al. due to the difference of specific size of injector but it is very similar. Also the increasing trend of Matas et al.'s result also appears in fig 3.7 and fig. 3.10. As momentum flux ratio increased from 1 to 2 which means the gas velocity increased, the low frequency peak moved from 200 Hz to 300 Hz. Consequently the low frequency peak is thought to occur due to amplifying interfacial instability when acoustic excitation frequency coincide with the frequency of interfacial instability. Therefore if disturbance of certain frequency which is matched to the interfacial frequency at designed momentum flux ratio occurred at feeding propellant, the response of film thickness would be violent. So gas liquid momentum flux ratio is significant parameter to prevent possible frequency of feeding propellant.

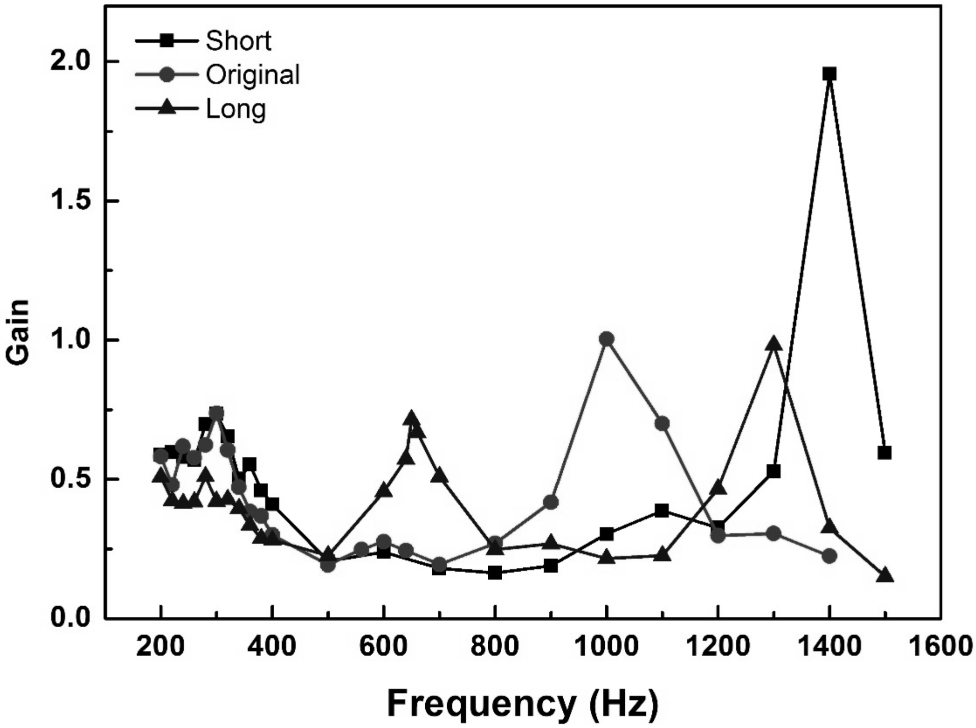

Figure 3.10 Line length change at MR=2.

3.4 Effect of momentum flux ratio

When the liquid mass flow rate was constant and momentum flux ratio was changed, the gain on input frequency is shown in fig. 3.11. The gain is changed obviously by gas liquid momentum flux ratio.

The increase of momentum flux ratio means that the gas momentum is larger than the liquid momentum, thus the gas flow can transfer more momentum to liquid flow [13]. Therefore, the gas perturbation by the speaker influenced more in the liquid film and perturbation of liquid film at the injector exit grew so that the gain increased.

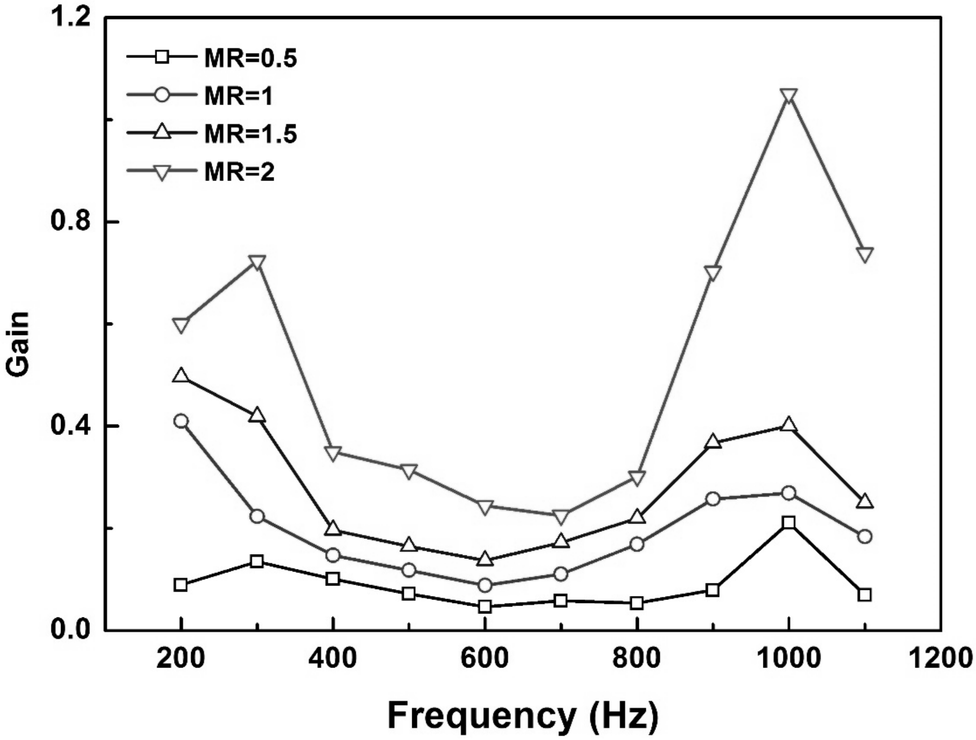

Figure 3.11. Effect of gas-liquid momentum flux ratio.

The increase of gain means the response of film thickness becomes larger. Excessive fluctuation is connected to spray instability involved with combustion instability. We can't know the exact margin of gain which doesn't trigger the combustion instability. It is clear the gain should be controlled under certain point and in order to do gas-liquid momentum flux ratio should not be too high.

Also it is observed that the low peak frequency moved to higher frequency as increasing of gas-liquid momentum flux ratio. It supports the cause of low frequency peak.

3.5 Effect of injector geometry

3.5.1 Recess Ratio

Recess ratio is significant parameter in gas liquid injector. Recess is the region where liquid and gas is mixed before injected to combustion chamber. As longer the recess length is the better mixing efficiency is and it leads to good combustion characteristic. But if recess length is too long flash back can occur in injector and it can cause the failure of combustion. So the recess length should be carefully considered. In this chapter the effect of recess ratio is studied from the perspective of dynamic characteristic.

Figure 3.12 shows the response of film thickness at recess ratio = 1 which means the diameter of gas orifice is same as the recess length. Fig. 3.13 and fig. 3.14 are recess ratio = 2 and recess ratio = 3 case each. The trend that low range frequency peak moves as the momentum flux ratio also appeared at all recess ratio condition. And the high frequency peak doesn’t move and it appeared at 1000 Hz at all comdition.

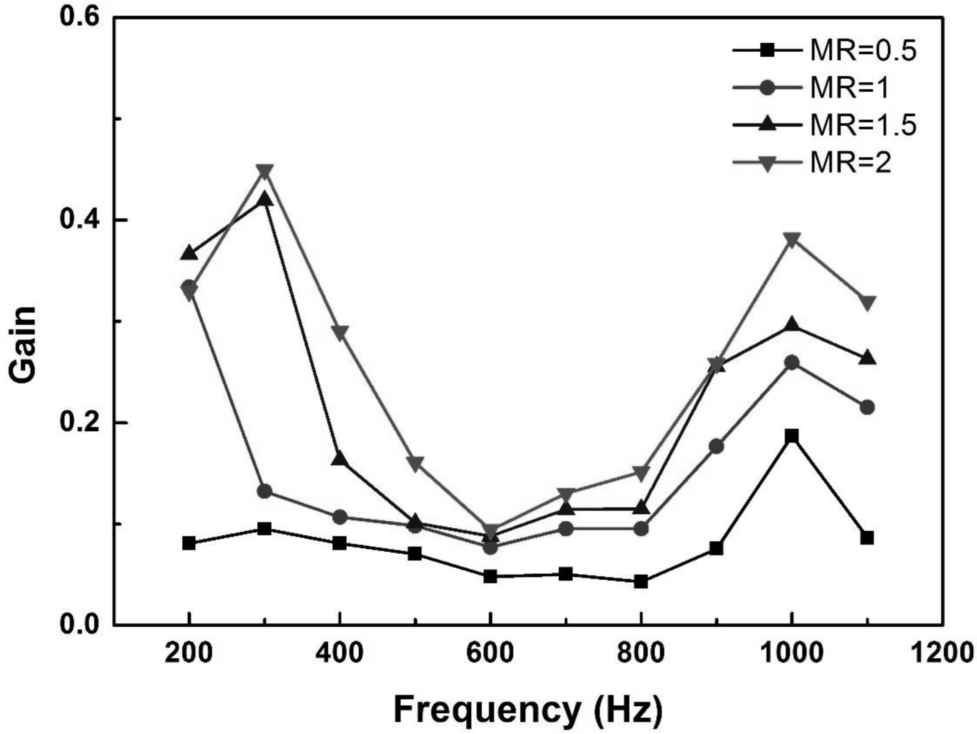

Figure 3.12. Gain versus frequency at Recess Ratio = 1.

The overall trend of gain was simillar regardless of recess ratio but the degree of increasing was very different. Not only the frequency of peak but also the magnitude of gain is significant because it is predicted that there will be margianl point of stable combustion. Though we can not pick up the exact point yet it is reasonable that lower gain leads to stable combustion when disturbance of feeding propellant exists. This phenomenon comes from increasing of mixing length. In long recess region gas and liquid can interact eachother more easily [13]. So the disturbance of feeding gas deliverd to liquid much more and the value of gain increased.

The highest peak of MR=1 case was only about 0.4 which means that the fluctuation ratio of film is 40% of the feeding gas velocity fluctuation ratio. That of MR = 2 case was about 1.1 in fig. 3.13. That of MR = 3 was about 1.9. The gain increased rapily according to recess ratio. So again it is verified that recess ratio is very important parameter in dynamic characteristic. In the view of surpressing combustion instability it is recommended that recess ratio should not be too long.

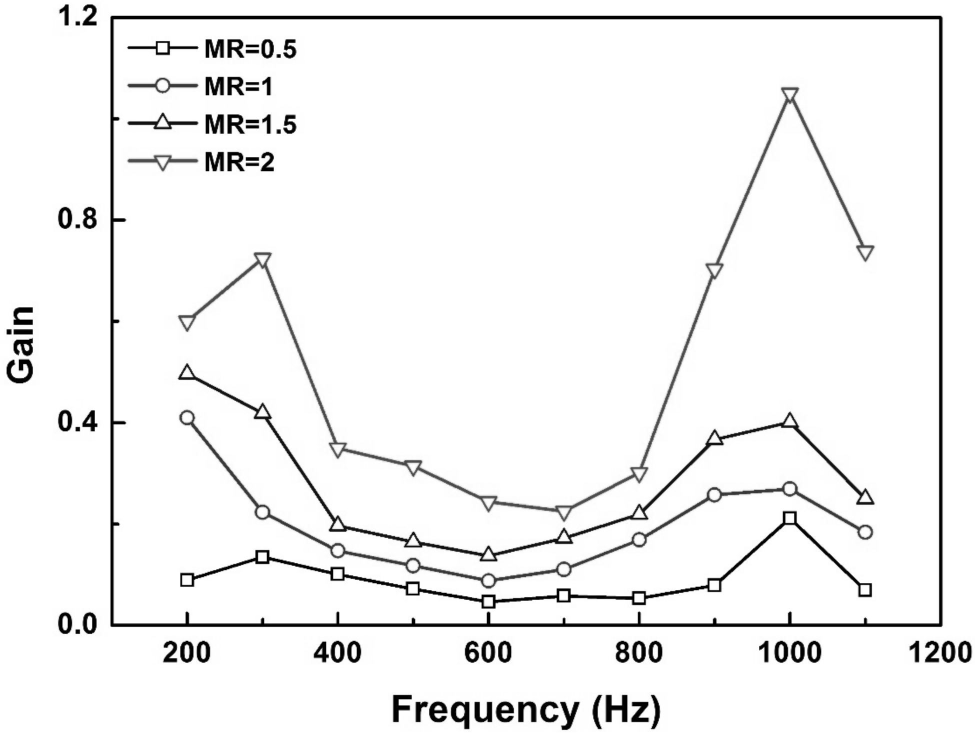

Figure 3.13. Gain versus frequency at Recess Ratio = 2.

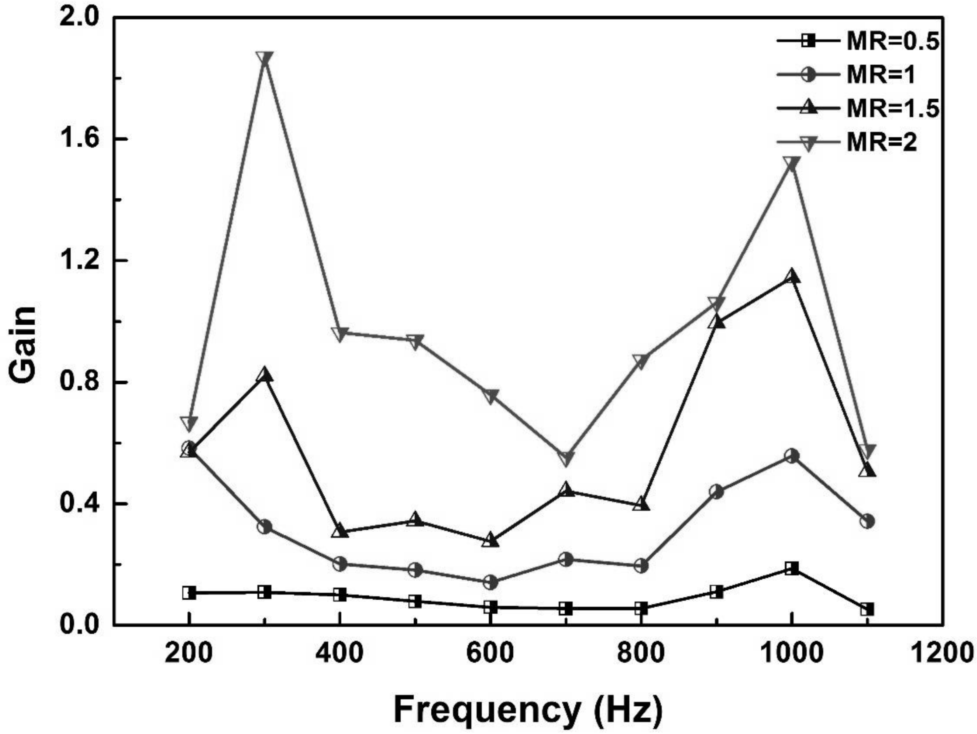

Figure 3.14. Gain versus frequency at Recess Ratio = 3.

Figure 3.15 shows the effect of recess ratio when varying gas liquid monentum flux ratio. Straight line is recess ratio = 3 case and dash line is recess ratio = 1 case. Cirlcle symbol is momentum flux ratio = 1 case and triangle is momentum flux ratio = 0.5 case. The influence of momentum flux ratio increase certainly when recess ratio is large. In recess ratio = 1 case largest growth of gain as the increasing of momentum flux ratio was about 0.1. In recess ratio = 3 case largest growth of gain as the increasing of momentum flux ratio was about 0.4 which is four times larger than recess ratio = 1 case. So recess ratio should be considered complexly when momentum flux ratio is determined.

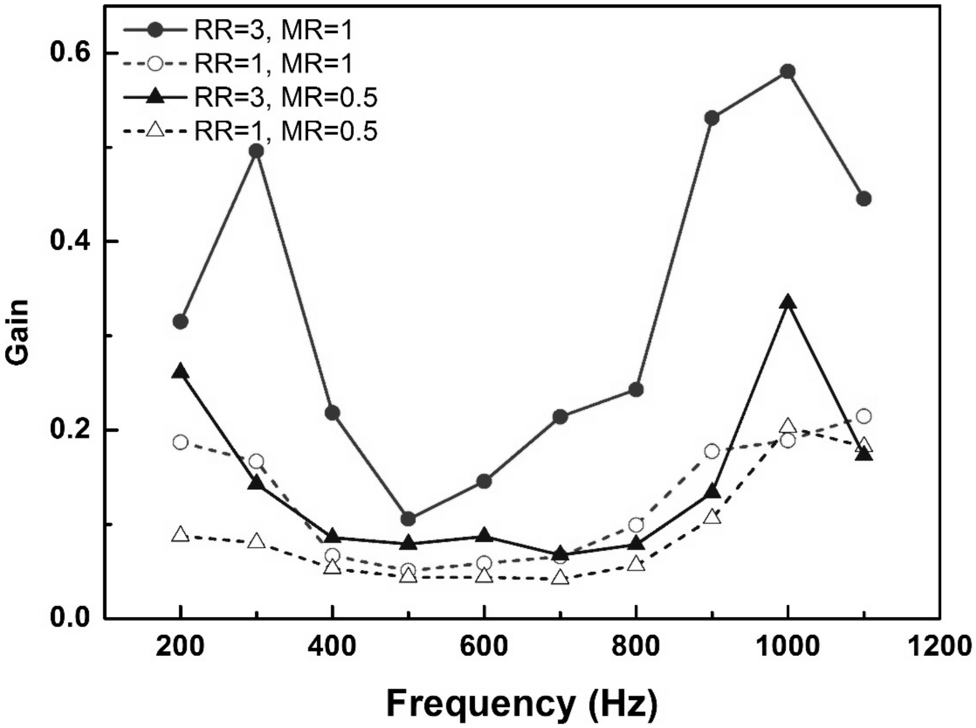

Figure 3.15 Effect of Recess Ratio.

These recess results also can be compared with liquid pulsation experiment. In the experiment of single swirl injector with liquid pulsation by Kim et al. when the chamber length increased the fluctuation of liquid film decreased because of friction and dissipation. In this study liquid pulsation didn't conducted but the trend can be predicted by Kim et al.' result. When recess length increased the disturbance of liquid by liquid pulsation decreased because passing length increased to dissipate [14]. But in this study, when recess length increased the disturbance of liquid by gas excitation increased because mixing length became longer in contrast with liquid pulsation case. So it imply that there can be optimal recess length which has good characteristic for both disturbance case which is feeding liquid pulsation and feeding gas excitation.

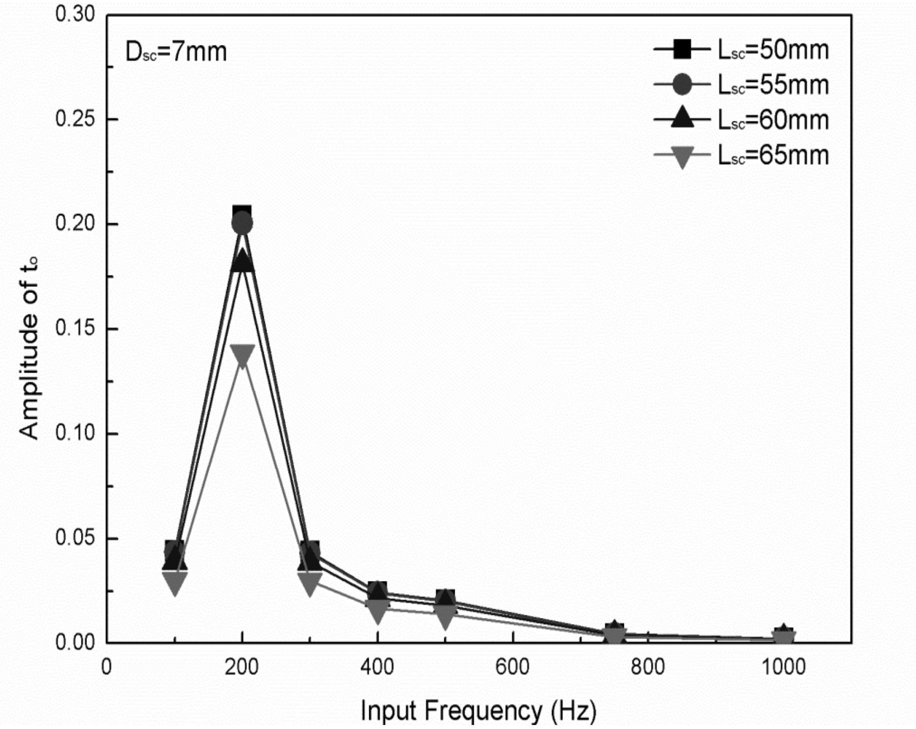

Figure 3.16 Effect of chamber length in liquid pulsation from Kim et al [14].

3.4.2 Gap thickness

The gap thickness that determined the initial film thickness influenced the film thickness as well as the spray angle. The gain on the gap thickness is shown in Fig.8. Color symbol was MR = 0.5 case and hollow symbol was MR = 2 case. At each momentum flux ratio case the response of three different gap thickness was observed. In low momentum flux ratio, the gain wasn’t changed nearly as the gap thickness increased. It means that the effect of gap thickness was minor in low momentum flux ratio. However in high momentum flux ratio, the gain increased certainly as the gap thickness increased. The effect of gap thickness was major in high momentum flux ratio. So when design point of momentum flux ratio is high the gap thickness should be considered. When the gap thickness is small, the initial thickness of film is small and disturbance is transferred more by getting more of gas influence. When the gap thickness is big, the initial thickness of film is thick and it becomes insensible to disturbance of feeding gas.

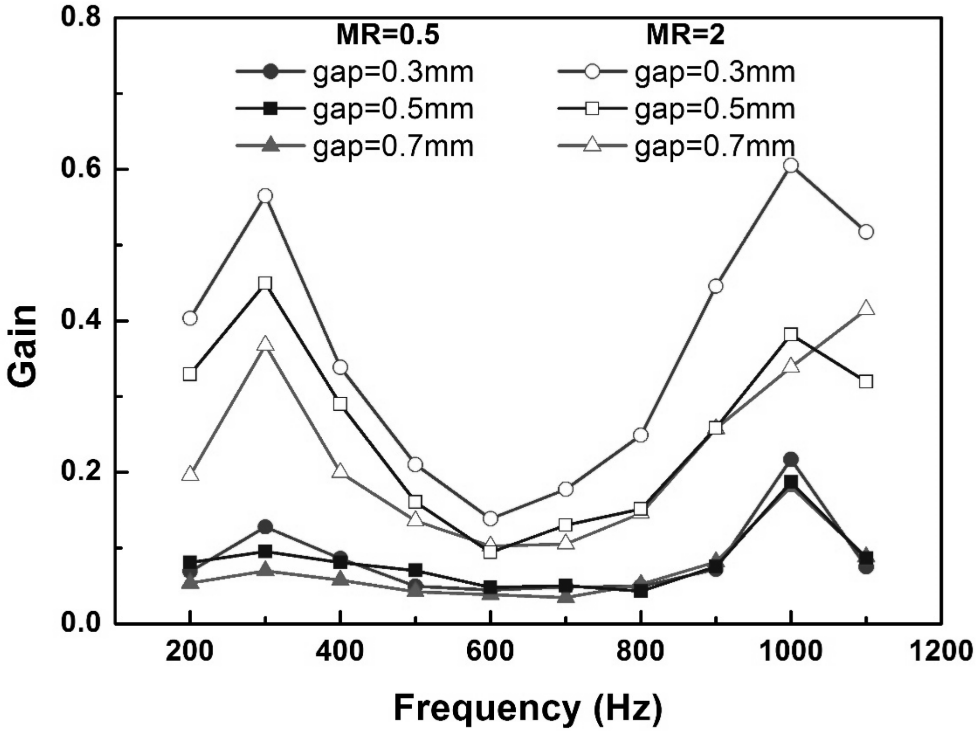

Figure 3.17 Variation of gain with gap thickness.

Chapter 4 CONCLUSION

An experiment of gas centered swirl coaxial injector was conducted to investigate dynamic characteristic. The Film thickness response with acoustic excitation of feeding gas in gas-centered swirl coaxial injector was measured by film thickness electrode and the spray behavior was observed by high speed photography. The disturbance frequency of feeding gas, gas-liquid momentum flux ratio, recess ratio, gap thickness were changed to investigate the effect of these parameters.

1. Response of film thickness varies with the frequency of disturbance. Two peak points which gain is much larger than others exist. The cause of peak point was two, feeding line length and natural perturbation frequency.

2. As gas-liquid momentum flux ratio increase, the response of film thickness increased because momentum transfer between gas and liquid increases according to the momentum difference of gas and liquid.

3. As the recess ratio increases, the response of film thickness increased because mixing length become larger.

4. As the gap thickness increases, the response of film thickness decreased because it restricts the initial film thickness.

Combustion instability problem can be improved with optimal design of injector considering dynamic characteristics by suppressing the disturbance of feeding propellants.

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초 록

액체 로켓 엔진에서 가장 주요한 문제로 여겨지는 연소불안정은 연소실 내의 연소와 추진제 공급시스템의 유동이 결합되어 발생하는 현상이다. 이러한 연소불안정 현상은 기본적으로 엔진의 연소효율을 악화시키고 제어장치들에 악영향을 줄 뿐 아니라 심하게 발생하는 경우에는 엔진의 파괴로까지 이어지게 된다. 이제까지 이러한 연소불안정 현상을 해결하기 위해 앞선 로켓엔진 개발국들에서는 Baffle, Cavity 등 다양한 방법들이 시도되었다.

본 연구에서는 연소불안정을 억제하고자 하는 이러한 노력의 일환으로 그 방안을 인젝터를 통해 찾고자 하였다. 연소불안정 현상을 야기하는 원인 중 하나로 공급되는 추진제의 교란이 있는데, 이러한 교란은 다양한 이유로 발생하게 될 수 있다. 교란은 연소실로 전파되고 그 영향이 공급시스템으로 되돌아오는 피드백 과정을 거치며 증폭될 수 있기 때문에 이러한 연쇄과정의 중간에 위치한 인젝터의 설계가 매우 중요하다. 인젝터가 일종의 완충장치의 역할을 하여 공급라인에서부터 들어오는 교란을 억제할 수 있다면 연소불안정을 저감하는데 기여할 수 있을 것이다. 그러나 앞선 관련 연구들은 주로 단일 스월 인젝터에서 액체교란에 대한 응답만을 대상으로 하였고 기체-액체 인젝터에서 일어날 수 있는 기체 추진제의 교란에 대한 현상은 많이 연구가 진행된 바가 없다.

본 연구에서는 기체 중심 스월 동축형 분사기에서 기체 추진제가 유동의 교란을 가진 상태로 공급되는 상황을 모사하여 스피커를 통하여

교란을 발생시켜 그 응답특성을 확인하였다. 분무각, 분열길이, SMD등 다양한 분무특성에 영향을 끼치는 인젝터 출구 액막 두께를 액막 측정 전극을 이용하여 측정하여 분석하였다. 또한 외부 분무를 고속카메라로 촬영하여 교란에 대한 응답을 확인하였다. 실험 변수로 분사기 리세스 비, 갭 두께, 기체-액체 운동량 플럭스 비, 공급교란의 주파수를 설정하여 변화시켜가며 그 영향을 파악하였다.

주요어: 액체로켓엔진, 기체 중심 스월 동축형 인젝터, 연소불안정, 동특성, 기체 가진, 리세스 비.

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