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SOUND REDUCTION BY USING ACOUSTIC RESONATORS FOR PAYLOAD FAIRING OF SMALL LAUNCH VEHICLE

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Abstract

To protect a satellite and electronic equipment from the acoustic loads generated by rocket propulsion system, many launch vehicle use acoustic blankets. Most high frequency region of the acoustic loads is reduced by nose fairing skins and acoustic blankets, but the low frequency region is not. In order to control low frequency acoustic mode, we designed an array resonator panel which was made of composite materials. Acoustic resonator has non linear characteristics in high-amplitude sound. This paper shows the absorption coefficient measurement result of resonators and sound reduction by using resonators in the payload fairing.

1. INTRODUCTION

Many launch vehicles use acoustic blankets in order to protect a satellite and electronic equipment from the acoustic loads generated by rocket propulsion system. Acoustic loads are main source of random vibration working on the payloads. Most high frequency region of the acoustic loads is reduced by payload fairing skins and acoustic blanket, but low frequency region is not. To reduce random vibration level by acoustic loads of low frequency region, we designed array resonator panel which was composed of composite materials and foam. This acoustic resonator has non linear characteristics in high-amplitude sound. Internal acoustic level of PLF (Payload Fairing) is dependent on its acoustic mode. We can decide the arrangement of resonators from acoustic mode analysis of the cavity of PLF. Insertion loss capacity of the PLF with acoustic resonators was verified from PLF acoustic test in the acoustic chamber.

2. ACOUSTIC RESONATOR DESIGN

Acoustic mode analysis about PLF of small launch vehicle by using FEM is performed for design of resonator. Figure 1 illustrates acoustic mode analysis results below 100Hz. General absorbing porous materials has a little efficiency on low frequency region but Helmholtz resonator has high absorption coefficient characteristics at its resonance frequency. As depicted in Figure 1, the 1st and the 2nd mode appear as the longitudinal mode at 43Hz and 72Hz. The 3rd mode appears as the radial mode at 97Hz. From this analysis, resonators were designed to have 43Hz (the 1st mode of PLF) as resonance frequency.

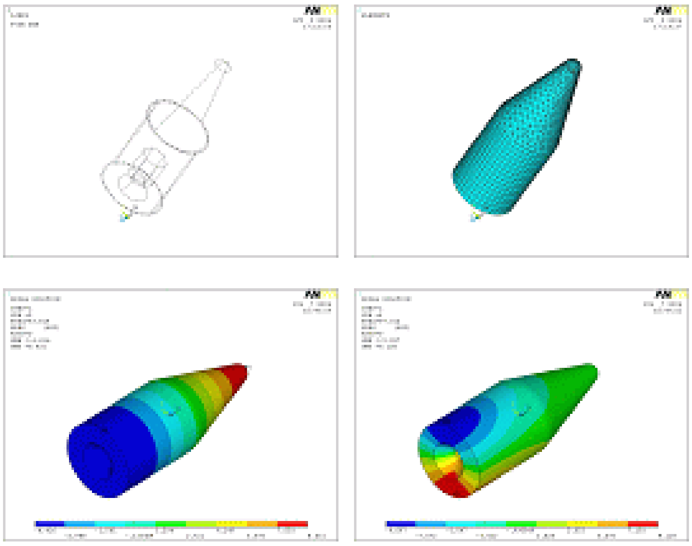
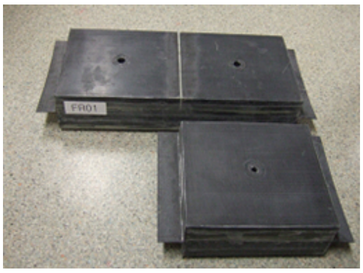


Figure 1 – Acoustic mode analysis of PLF

Figure 2 shows acoustic resonator panel assembly which are made of composite material. Resonator has basic shape that is composed of narrow neck and cavity. Absorption coefficient of resonators is measured by two-microphone method using transfer function [1], [2]. Generally launch vehicle generates acoustic loads more than 150dB during lift-off. Resonator has non linear absorption characteristics at high amplitude pressure. Considering this point, absorption coefficient was measured for several excitation pressure levels.



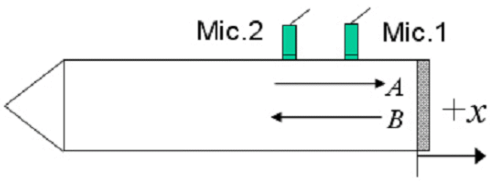
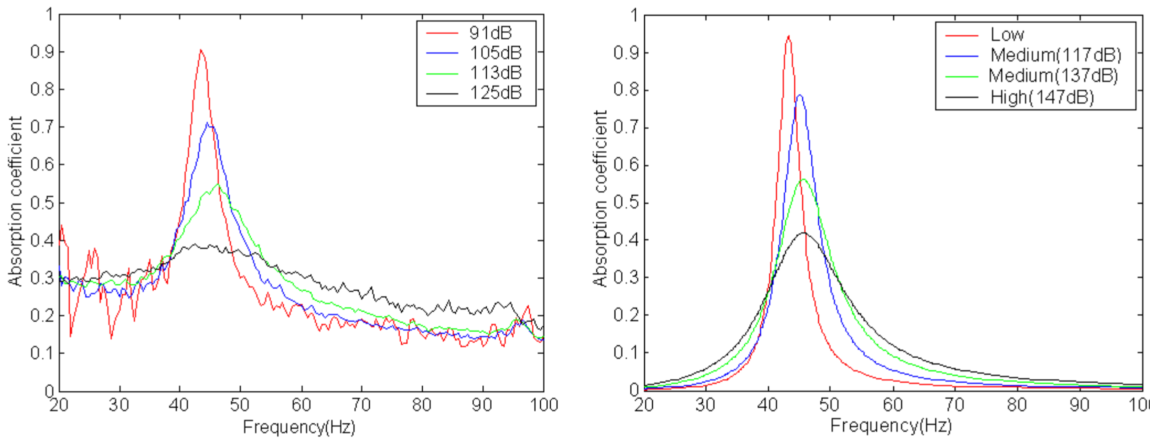


Figure 2 – Measurement of absorption coefficient of acoustic resonator

Figure 3(a) illustrates variation of absorption coefficient by changing excitation pressure level. As the excitation pressure level increases, the absorption coefficient peak shifts to low value and its bandwidth is broader. Resonance frequency also shifts to a little higher frequency (46Hz). This non linear effect is probably due to thermal and viscous dissipation [3], [4]. In order to predict non linear phenomena, the modified empirical impedance formula from this measurement results was calculated. Figure 3(b) shows analytical absorption coefficient of the resonator using modified resistance of empirical impedance formula [5], [6]. The predicted result shows quite good agreement with measurement result. This result shows that the resistance term of neck impedance increases with the excitation pressure level. This excitation pressure level is the predicted value of the inside PLF for acoustic test.



(a) *(b)*

Figure 3 – Variation of absorption coefficient for increase of pressure level (43Hz)
(a) Measurement result (b) Analytic prediction

Figure 4 illustrates the relation of absorption coefficient and excitation pressure level (Lp). This result shows characteristics of absorption coefficient while varying the excitation pressure level. As depicted in Figure 4, absorption coefficient increases below 90dB at the resonance frequency. On the other hand, it decreases above 90dB. That is, small orifice of resonator for low resonance frequency may induct disadvantage about sound reduction at high pressure amplitude environment. This resonator's porosity ($\varepsilon = S_h / S_c$) is nearly 0.13%. Here S_h is orifice area, S_c is cross sectional area of resonator cavity.

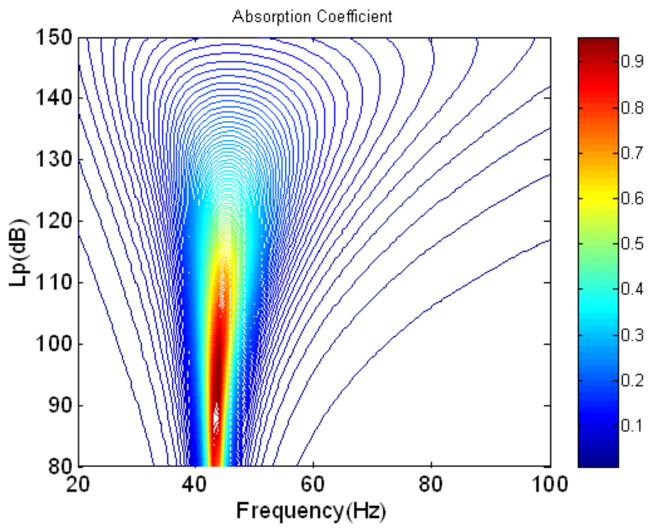


Figure 4 – Absorption coefficient varying pressure level (43Hz)

From this result, the 1st mode resonator's resonance frequency has too low frequency. To compare this non linear characteristic, the other resonator which is designed to have high frequency is tested. Figure 5 shows shape of new resonator for test. This small resonator's porosity is 1.96%. All absorption coefficient results are measured by duct having same cross sectional area with resonator's cavity in order to compare as porosity concept.

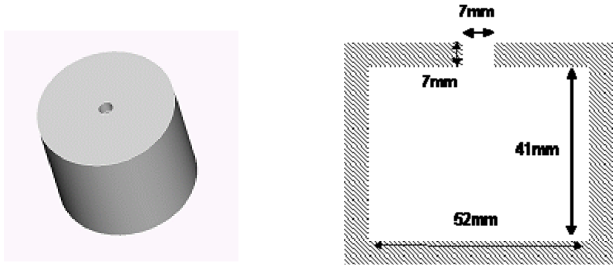
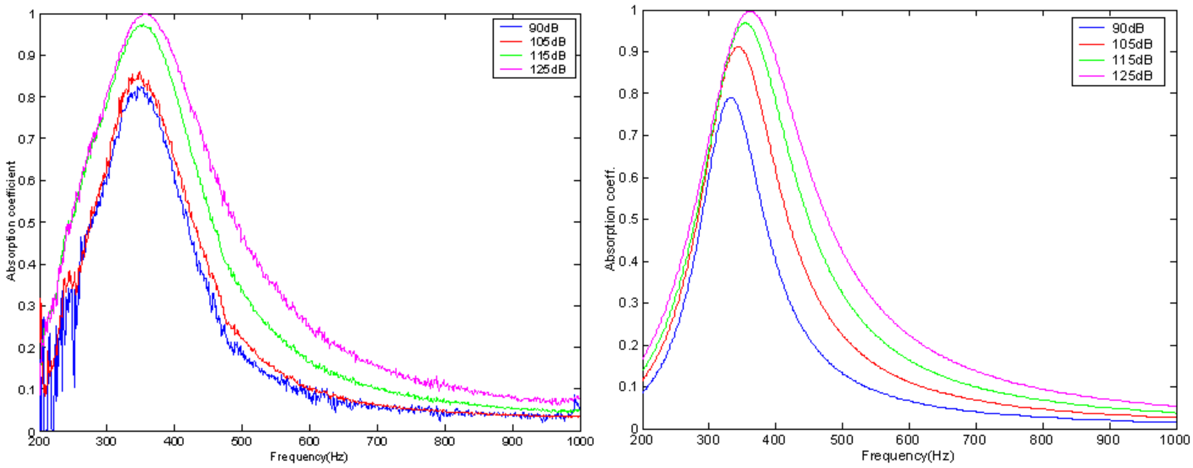


Figure 5 – Resonator specimen for absorption coefficient measurement (332Hz)



(a) *(b)*

Figure 6 – Comparison of absorption coefficient for increase of pressure level (332Hz)
(a) Measurement result (b) Analytic prediction

Figure 6 illustrates comparison of measurement and analytical prediction about absorption coefficient for excitation pressure level. This analytic prediction also based on the empirical impedance formula as stated above. As depicted in Figure 7, this resonator has maximum absorption coefficient value at about 130dB. From this prediction, absorption coefficient depends on excitation pressure level. This result shows that it is necessary to design resonators with considering sound pressure level of environment to be applied.

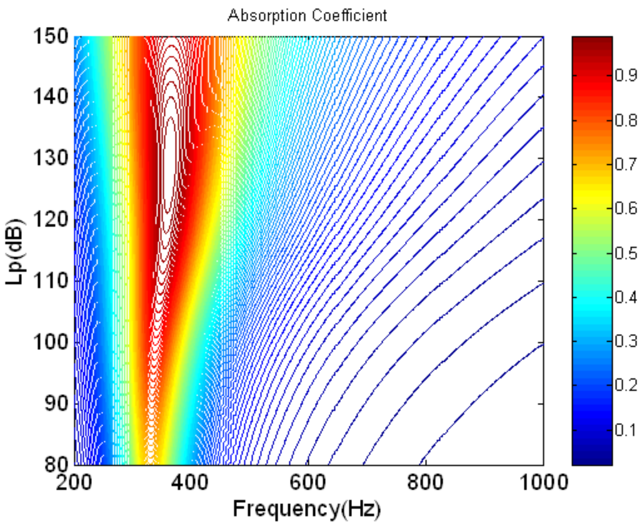


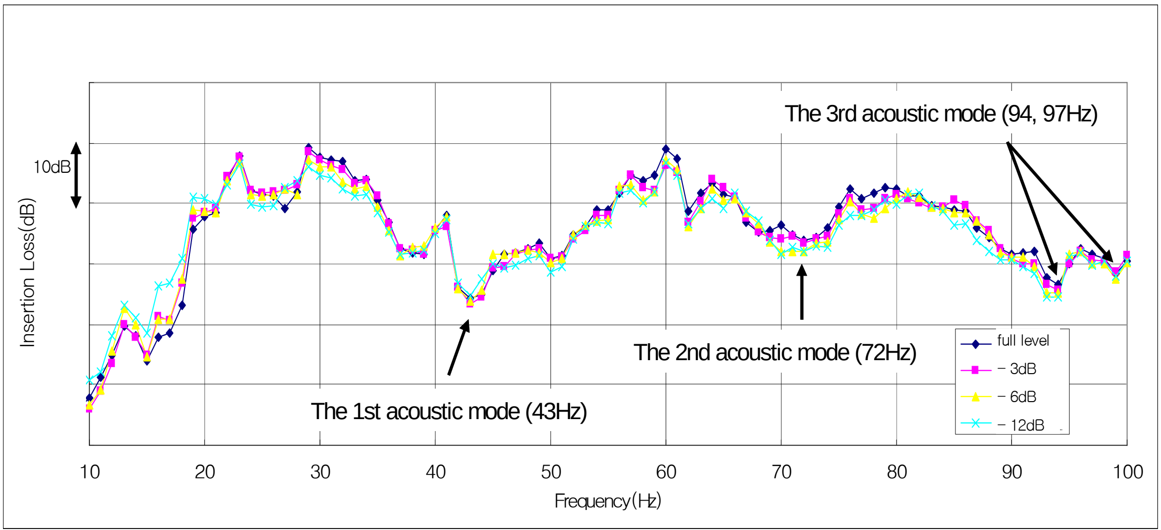
Figure 7 – Absorption coefficient varying pressure level (332Hz)

3. ACOUSIC TEST RESULTS

To verify sound reduction by resonators, this acoustic test was performed. Test specimen is a real scale upper stage of small launch vehicle including payloads. This test was performed in acoustic chamber which can excite to overall 148dB. Total 20EA acoustic resonators (the 1st mode) are applied at lower position of cylinder in the PLF. Figure 8(a), (b) show test specimen and insertion loss of PLF without acoustic resonators while varying excitation pressure level.

As depicted in Figure 8(b), there is little change of insertion loss while varying pressure level and acoustic modes appear at the valley of insertion loss curve. That is, insertion loss decreases at acoustic mode frequency. Purpose of acoustic resonator is increasing insertion loss locally.

(a)

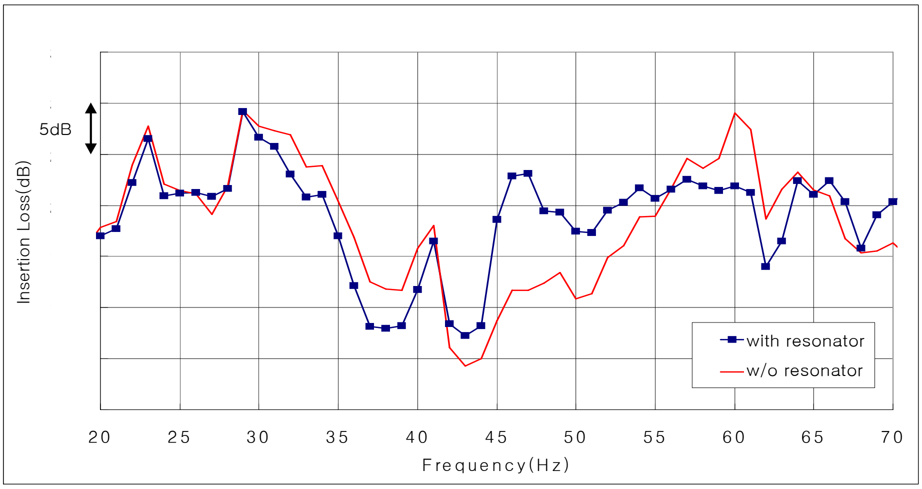


(b)

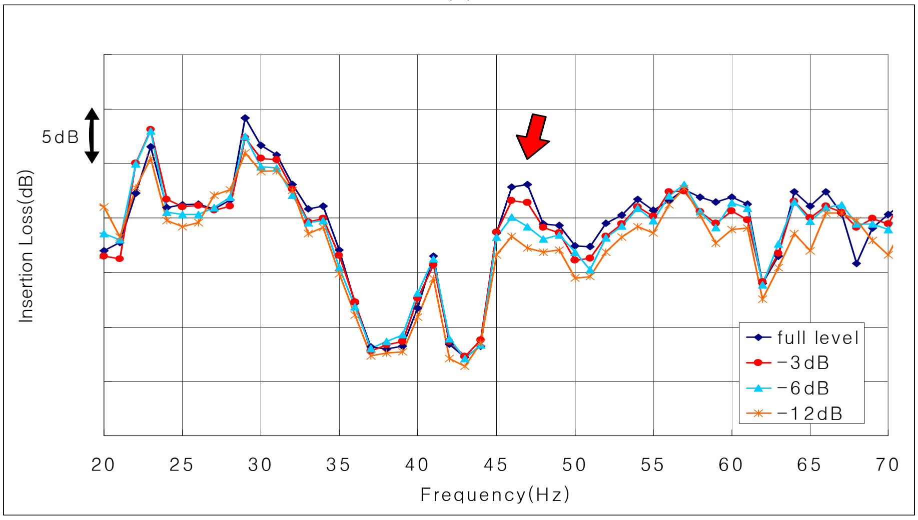
Figure 8 – Insertion loss of PLF without resonators

(a) Test specimen (b) Measurement result varying pressure level

Figure 9 illustrates comparison of insertion loss results of PLF with acoustic resonators while varying pressure level. This result shows the increase of insertion loss at the 1st mode frequency. Due to non linear characteristics of resonator orifice, the resonance frequency shifts to 46Hz. At this frequency, insertion loss increases gradually while varying pressure level. From this result, it is necessary to modify resonance frequency of resonator in order to agree with the 1st acoustic mode frequency of PLF. As a result of this acoustic test, we can verify the noise reduction capacity by using resonators.



(a)



(b)

Figure 9 – Comparison of insertion loss of PLF with resonators
(a) With/without resonators (b) Comparison while varying pressure level

4. SUMMARY

Acoustic mode analysis about PLF of small launch vehicle by using FEM is performed for design of resonator. Considering non linear characteristics of resonator orifice, absorption coefficient is measured for several excitation pressure levels. From measurement result, small orifice of resonator for low resonance frequency has disadvantage at high pressure amplitude environment. These results show that it is necessary to design resonators with considering sound pressure level of environment to be applied. To verify sound reduction by resonators, the acoustic test was performed.

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