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Noise Reduction Analysis Using Extended Neck of Helmholtz Resonator within Limited Engine Room

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Abstract

Automobile manufacturers have been researching for numerous years to comply with consumer demands and enhanced noise regulations, and to reduce the intake noise, which is the major cause to automobile noise. The acoustic performance of the Helmholtz resonator, one of the methods to reduce intake noise, has been verified and researched by both theory and experiment. The Helmholtz resonator has been used mostly to absorb noise in low frequency bands, but it has been difficult to design a desired resonant frequency according to the limited space of the engine room and other parts due to the limitation in bandwidth of the resonant frequency bandwidth. Therefore, in this research, resonance frequency and transmission loss are analyzed by extending the Helmholtz resonator neck into the resonator to lower the resonance frequency within the limited space. Within the limited space, the inserted neck of the Helmholtz resonator reduced the resonance frequency without increase of volume of the resonator and reduced the volume by 57% with the same resonance frequency as the resonator compared to the other resonance frequency that also is of 300 Hz.

Keywords: Helmholtz resonator, Intake noise, Resonator neck, Resonance frequency

INTRODUCTION

Automobile noise can be classified into two types: outdoor and indoor. The intake noise, which occupies about 30% of indoor-noise, is generally within 600Hz, low frequency noise. During this time, the intake noise is effective to improve the overall automobile noise by reducing the intake resonance noise due to the pressure pulsation of the air stream and the resonance of the indoor-noise during the combustion process of the engine. Normally, the Helmholtz resonator and the quarter wave tube are used as the main noise control means of the intake system. However, the Helmholtz resonator has limitation in space due to space issues in a narrow engine room, for instance, of a small car. Therefore, it has been difficult to design resonance frequencies that are required in using the Helmholtz resonators in limited spaces[1-3].

Recently, the quietness of the automobile became an indicator to measure the quality of the automobile. This research attempts to improve the quality of the automobile by reducing intake noise, which is one of the ways to improve the quietness of the automobile. Thus, it was confirmed that the noise was louder at 300 Hz than other frequency bands when experimented using a real automobile. The target frequency was set to 300 Hz in order to reduce the loud noise at 300 Hz, and the Helmholtz resonator with a large noise reduction effect in the low frequency band was used in order to deduct the intake noise. However, the existing 300 Hz resonator is hard to use due to its large volume in such limited space. Designing a resonator with a target frequency in limited space is difficult due to the lack of space. Therefore, for the design of a resonator with a resonance frequency of 300 Hz, which is smaller than the conventional 300 Hz resonator, the neck had been extended into the resonator in 10mm increments. Noise analysis was performed by comparing the resonator with the existing 300 Hz resonator and the extended neck.

HELMHOLTZ RESONATOR

The Helmholtz resonator is a combination of volume, neck length, and cross-sectional area, which is an effective acoustic damping device at low frequencies. Figure1 shows the simplified and typical Helmholtz resonator. As shown in the figure, the air is basically shaped like a jar, the neck air acts as a mass, and the air in the inside acts as a spring, causing resonance. Also during the resonance occurrence, air in the neck enters and exits, and is converted into thermal energy by friction with the tube wall [4-5].

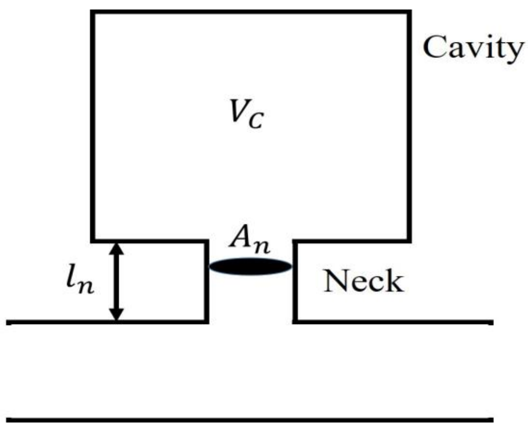

Figure 1: Schematic of a typical Helmholtz resonator

Resonance frequency (f_r) of the Helmholtz resonator can be predicted as the following:

$$f_r = \frac{c_0}{2\pi}\sqrt{\frac{A_n}{l'_n V_c}}$$

where $c_0$is the speed of sound, $A_n$is the cross-sectional area of the neck, l'_n is the effect length of the neck, and V_c is the volume of cavity. The effect length of the neck increases the accuracy of the resonance frequency prediction by adding the correction length to the measurement length (l_n) of the neck. It can be seen that as the cavity volume increases or the effect length of the neck increases, the resonance frequency decreases. However, the volume increase is limited to a narrow engine room. Thus, the neck extension is effective in lowering the resonance frequency [6].

TRANSMISSION LOSS

Transmission loss is an algebraic representation of the energy transmitted and the energy passed through the silencer. Acoustic output (W_i) delivered through the silencer is defined by the ratio of the acoustic output of the silencer(W_t).Transmission loss can be expressed as the following:

$$\mathrm{TL} = 10\log\frac{W_t}{W_i}$$

Large transmission loss means that the information of the sound wave does not pass well. It is used as an indicator to evaluate the resonator performance. Thus, in this research, transmission loss was used as an indicator to evaluate the resonator performance according to the length of the neck [7].

NOISE ANALYSIS ACCORDING TO THE NECK LENGTH INSERTED ON THE HELMHOLTZ RESONATOR

Analysis Modeling

The results of experimenting with an actual automobile showed that the Helmholtz resonator, which has a high noise level at a low frequency of 300 Hz, had been used for deducting noise. The Helmholtz resonator with the target resonance frequency requires a volume of 2.25×10^{5}mm^{3}in order to deduct noise of targeted 300 Hz. However, it cannot be used in a limited space, such as a narrow engine room or an accessory part. For use in a limited space that does not interfere with the narrow engine room and accessory parts, it is necessary to produce a resonator with the volume of 1.28×10^{5}mm^3 or less. Thus, it is necessary to produce a resonator with a reduced volume with a resonance frequency of 300 Hz. In order to produce the Helmholtz resonator with reduced volume with a resonance frequency of 300 Hz, we used a method to lower the resonance frequency by extending the neck into the resonator. Figure 2 and Table 1 are the basic information and dimensions according to the case of the Helmholtz resonant.

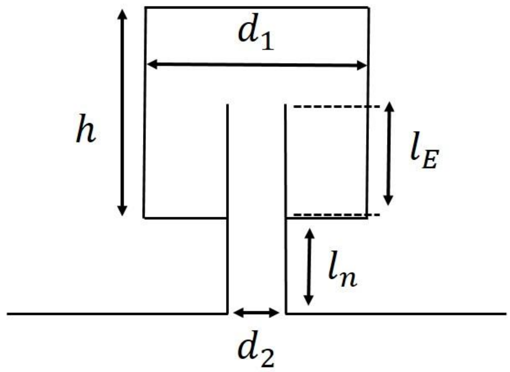

Figure 2: Schematic of a Helmholtz resonator

Case 1 is a Helmholtz resonator with a resonance frequency of 300 Hz. Case 2~6 are modeled for limited space 1.28×10^{5}mm^3, and the resonator neck was modeled by inserting 10mm into the resonator according to the case. The diameter of the neck d_2 and length of neck l_n of all cases were modeled as 20mm and 30mm. Figure 3 shows the intake part model used for the analysis. It includes a snorkel to suck in air, an intake duct before an air cleaner, and a Helmholtz resonator modeled according to the case.

Boundary condition

In order to materialize the noise generated from the engine during the analysis through the air duct and resonator to flow out from the intake snorkel, the following properties and initial conditions were used. Figure 3 shows the location of boundary conditions. A is the start of the air cleaner, Acoustic port, and B is the acoustic port 2, where the sound is set in the direction from B to A.

Table 1: Value of each Helmholtz resonator model case

Model	Value	Extended neck length (l_E)
Case 1	Height (h) : 66mm Diameter of cavity (d_1) : 66mm	0mm
Case 2	Height (h) : 55mm Diameter of cavity (d_1) : 55mm Diameter of neck (d_2) : 20mm Neck length (l_n) : 30mm	0mm
Case 3		10mm
Case 4		20mm
Case 5		30mm
Case 6		40mm

※Case 1: Existing resonator with resonance frequency of 300 Hz

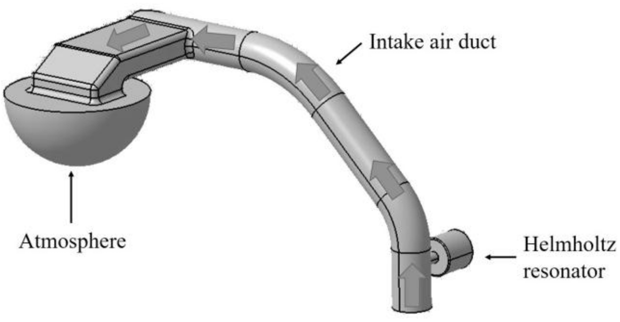

Figure 3: Intake system model with resonator

Table 2: Simulation boundary condition

Condition	Value
Mass Density	1.2041 (kg/mm^3)
Sound Speed	343.24 (m/sec)
Dynamic Viscosity	1.783×10^5 (Pa · sec)
Bulk Viscosity	1.096×10^5 (Pa · sec)
Specific Heat C_p	1.005 (J/Kg·℃)
Specific Heat C_v	0.718 (J/Kg·℃)
Reference Pressure	2.0×10^5 (Pa)
Reference Static Pressure	101,325 (Pa)

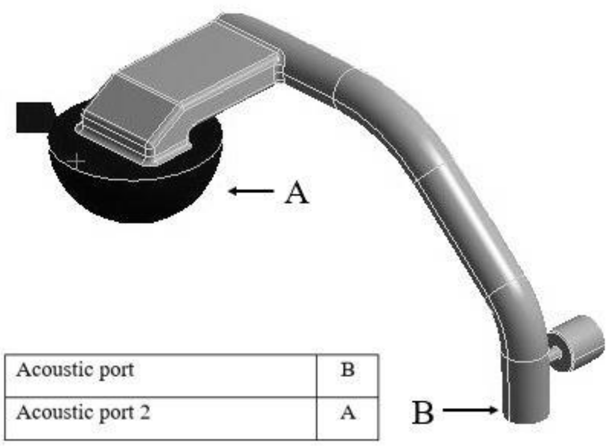

Figure 4: Position for boundary condition of analysis model

Analysis results

The transmission loss for each case is shown in Figure 5, and the resonant frequency and maximum transmission loss are shown in Table 3.The transmission loss of the Helmholtz resonator Case 1 with a target frequency of 300 Hz was 43 dB and the resonance frequency of the resonator Case 2 without the neck inserted at a limited space of 1.28×10^{5}mm^3 was found to be 395 Hz and the transmission loss to be 48 dB. Comparing with Case 2, the resonance frequency of Case 3 ~ 6 with 10mm of neck insertion was deducted as the depth of the inserted neck was increased to 364 Hz, 339 Hz, 319 Hz, and 300 Hz. Comparing Case 1 and Case 6, the volume decreased by 57% with the same resonance frequency. The Helmholtz resonator with its neck inserted can be made smaller in volume than the Helmholtz resonator with the same target resonant frequency, so the engine space can be used more efficiently.

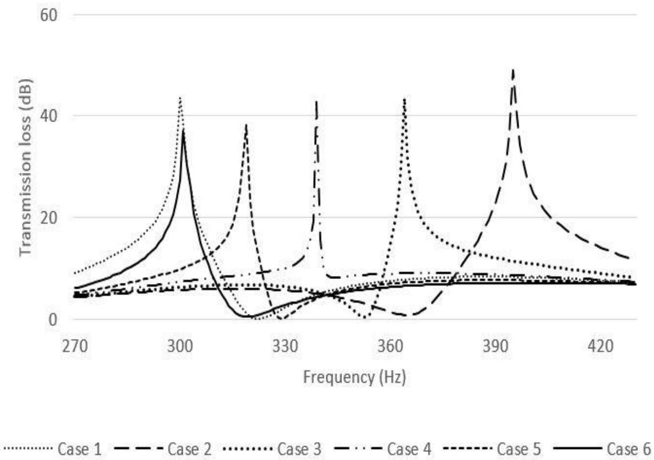

Figure 5: Transmission loss according to case

Table 3: Resonance frequency and transmission loss for each cases

	Resonance frequency	Maximum Transmission loss
Case 1	300Hz	43dB
Case 2	395 Hz	48 dB
Case 3	364 Hz	44 dB
Case 4	339 Hz	33 dB
Case 5	319 Hz	38 dB
Case 6	300 Hz	37 dB

CONCULUSION

In this research, noise analysis is performed on the intake duct of the intake system and the Helmholtz resonator, and the following results are obtained as the insertion of the Helmholtz resonator is carried out.

1) In a limited space, the inserted neck of the Helmholtz resonator can deduct the resonant frequency without increasing the volume of the resonator.

2) Inserted neck of the Helmholtz resonator deducted the resonance frequency of the existing model 395Hz by 31.6% to the target frequency of 300 Hz.
3) The inserted neck deducted 57% of the volume with the same resonance frequency as the existing 300 Hz resonator.

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