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Air Intake Noise Reduction of using a Turbocharger Engine in Vehicles

Jongwoo Park[1], Byungmo Yang[2] and Haengmuk Cho[1*]

[1]Division of Mechanical and Automotive Engineering, Kongju National University, Chungnam, Republic of Korea.
[2]Division of Division of Mechanical Engineering, Kongju National University, Chungnam, Republic of Korea.
**Corresponding author,*

Abstract

Tire noise, road noise, wind noise, combustion noise, inhalation noise, etc. impacted the interior noise of an automobile. Automobile companies have worked hard to reduce the interior noise and now we have comparably less vehicle interior noise. However, the engine miniaturization and the equipment of turbochargers act as a noise source in certain sections these days. However, there is a disadvantage due to the supercharger that noise in a particular section upon rotation of the turbine hiders driving comfort. And, resonance noise in the intake system or noise in the combustion process is produced, as air supercharging occurs in the compressor to increase the output upon a burst of speed. In the present study, intake resonance noise in the air intake process, which is one of the major noises causing unpleasantness for passengers inside among such noises, will be investigated.

Keywords: Air Intake system, Intake noise, Resonator, Turbocharger noise

INTRODUCTION

Recently, environmental problems due to emission of carbon dioxide as the culprit for warming are emerging globally. Although changes are also taking place in the automotive industry due to such environment problems, eco-friendly vehicles such as HEV(Hybrid Electronic Vehicle), PHEV(Plug-in Hybrid Electronic Vehicle), EV(Electronic Vehicle) and FCEV(Fuel Cell Electronic Vehicle) with advantages in environment problems still have a difficulty in popularization due to lack of the infrastructure. In such situations, the automotive industry satisfied customers' requirements by lowering displacement volume in the existing engines and applying turbochargers. However, importance of NVH for automobiles was also emerged recently according to an enhanced level of consumer requirements, where various noises and vibrations have become a problem.

Engine noise can be categorized into aerodynamic noise, combustion noise, mechanical noise according to the characteristic of the noise, and into the exhaust system noise, intake noise, cooling system noise and engine system noise according to the source of the noise. The noise emitted from the intake and exhaust system due to the internal movement within the engine has been a crucial problem in dealing with the interior and the exterior noise emitted from the vehicle. There has been research on the form of the sub systems such as the muffler, and on their positioning to reduce said noise. [1]. Intake resonance noise as the part inducing the largest noise along with aerodynamic noise among the whole noises of an automobile appear generally in a basic frequency of 20~200Hz at 600 ~ 6000rpm together with 2nd and 3rd harmonic frequencies. Intake noise occurs from engine start-up, and the largest noise occurs particularly when the frequency of pressure change due to explosion coincides with the resonance frequency of the intake duct. To reduce such intake resonance noise, mounting of a resonator corresponding to the resonance frequency of the intake duct from the design stage has been popularized. As a result of reducing the intake noise which hinders passengers' driving comfort inside the vehicle, completeness of automobiles was enhanced, and several advantages such as securing spaces inside the complicated engine can be expected with optimization of the form of resonator as a reduction apparatus for intake noise[2-4].

In the present article, recent study trends on reduction measures for the noise produced in the engine intake system will be comprehensively discussed, and the future development directions for intake noise reduction systems will be presented by analyzing basic flow and noise through finite element analysis simulation (ANSYS Fluent).

NOISE OF INTAKE SYSTEM

Cause for Occurrence of Intake Noise

Intake noise among the noises occurring in a vehicle is primarily Airborne Noise produced in the engine. This noise is low in temperature, and is propagated in the opposite direction to that of intake flow. The intake noise is a noise produced as the air column within the intake tube is vibrated according to pressure change as a result of opening/closing of the intake valve. The equation (1) exhibiting the characteristic of the intake noise is as follows.

$$f(Hz) = n \times rpm \times \frac{c}{2} \times \frac{1}{60} \qquad (1)$$

Where 'f' is the intake noise frequency, 'n' the harmonic degree, 'rpm' the number of engine revolution, 'c' the number of cylinders.

Main causes for occurrence of the intake system include noise due to surface vibration of intake system tube or air filter box, etc., and abnormal flow of fluids due to intake valve and turbulent flow around the throttle.

High-frequency noise above about 1,000Hz of broad band relatively easy to be attenuated is produced by this turbulent flow. When the fluid enters in the cylinder as the intake valve is opened the minimum pressure occurs, and a large pulsation is produced as kinetic energy of the fluid is converted to pressure energy when the intake valve is closed. Namely, longitudinal waves having a basic form of compression is produced. While the trough of pressure due to intake action at low speeds is about 1/2 of the pressure pulsation, they become similar at high speeds. Such pressure trough s and peaks from each valve become a noise source to realize noise radiation by being merged in the throttle body.

While such noise is relatively difficult to attenuate, the noise radiated from the noise source resonates according to stationary waves related to a length of the intake system, and the noise finally radiated from Snorkel Aperture is a result where such sound source characteristics and resonance characteristics of the system are overlapped[5].

Reduction Methods for Intake Noise

Methods for reduction of noise are largely divided into 3 types, which include the method of installing a resonator, the method of using a sound-absorbing material, and application of a particular groove shape at compressor inlet. Recently, as studies on optimum design of resonators are being actively conducted to enhance completeness of vehicles, those include porous duct capable of reducing the number of resonators for intake system albeit a high production unit cost and reverse flow-type silencer where a resonator applied to air cleaner interior is attached without outside exposure of the resonator. Also as a measure for optimum improvement of intake flow sound, diversified studies are being conducted on optimum shapes of the groove positioned at the compressor inlet.

Noise reduction by using sound-absorbing material

Porous duct is a duct with a circular section with the wall reinforced by wire for woven fabrics. In other word, the porous duct applied to the automotive intake system does not exhibit the characteristics as a resonator. However, intake noise at particular frequencies is reduced by using the porous duct for the plastic duct part after air cleaner. The principle for noise reduction by porous duct with diversified porosities is that the porous duct wall plays a role of a sort of sound-absorbing material since the sound is leaked out through the duct wall[7-8].

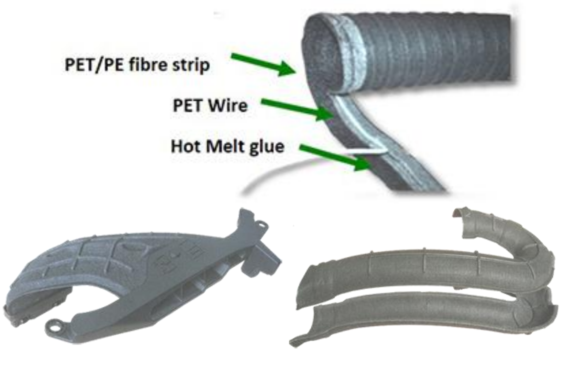


Figure 1: Porous type duct of intake system

Reverse flow-type silencer with attachment of resonator

Reverse flow-type silencer is used mainly in a form of air cleaner rather than being used as an acoustic element due to spatial problems. Since it changes the direction of fluid flow and sound wave propagation to the opposite one, a large transmission loss occurs in comparison with a simple expansion-type silencer, and such form causes degradation in engine performance by inducing a high negative pressure although noise attenuation in low-frequency regions is particularly outstanding. The reverse flow-type silencer has advantages that it is suitable to the cases with narrow spaces in the engine room due to applicability to the air cleaner and that no outside exposure of the resonator allows enhancement of completeness. According to the measured results for transmission loss, the maximum value is observed at a particular frequency according to the resonator in addition to the characteristics of a simple expansion-type tube or a reverse flow-type silencer.

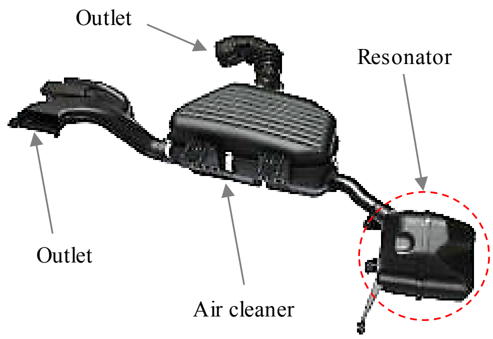
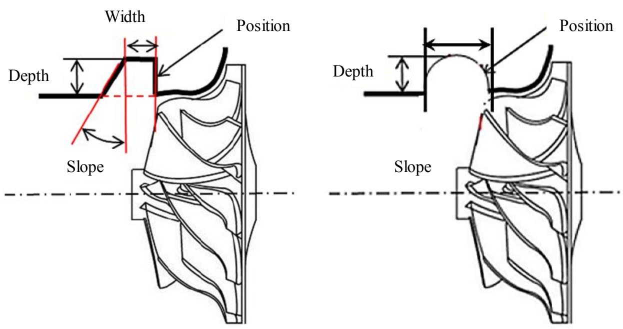


Figure 2: Resonator of air intake system

Application of optimum groove shape at compressor inlet

As a measure for optimum improvement of intake flow sound, square or circle was considered for the shape of the groove positioned at the compressor inlet in Figure 3. The optimum groove shape achieved the target level for indoor noise in the state of maintaining turbocharger performance, and it was learned that the groove at the compressor inlet was effective not only for reduction of flow noise in a narrowband but also for reduction of flow noise in a relatively broadband. When a groove with diversified shapes was applied to the compressor inlet, the shape with relatively excellent noise reduction effects was a square groove rather than a circular groove, and not only the flow noise of narrowband but also that of a broad region with high frequency was affirmed to be applicable for the reduced noise[9-13].



(a) Rectangular grooves (b) Round grooves

Figure 3: Grooves of automotive turbocharger

Active Noise Control (ANC)

As seen in Figure 1, active noise control aims to utilize the principle of superposition and create an anti-noise that has the same volume of sound and the opposite phase as the noise that is to be reduced.

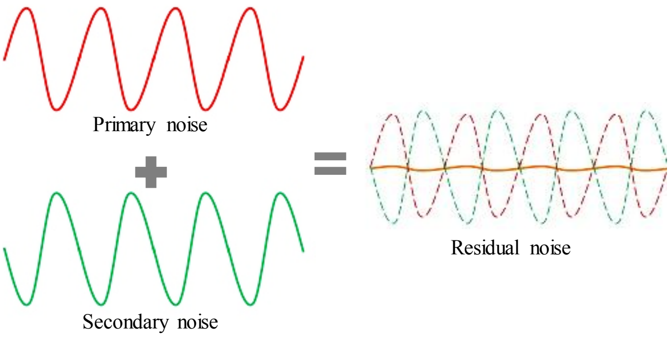


Figure 3: Principle of active noise control (ANC)

The booming noise, caused by the coupled effect from the structures and sound medium, is typically a low frequency noise. It is believed that using active noise controllers is more effective in controlling such low frequency noise than using sound absorption materials. Figure 1 is a graph outlining the active noise controlling system.

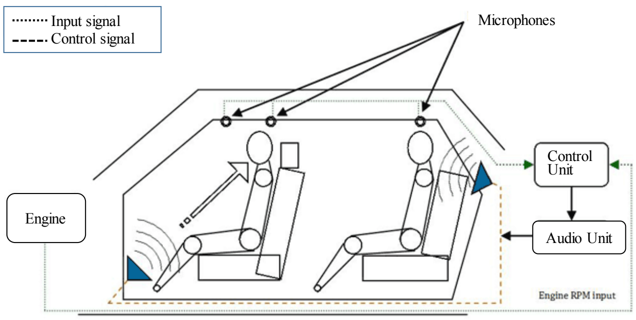


Figure 3: Principle of active noise control (ANC)

FLOW AND NOISE ANALYSIS FOR INTAKE SYSTEM

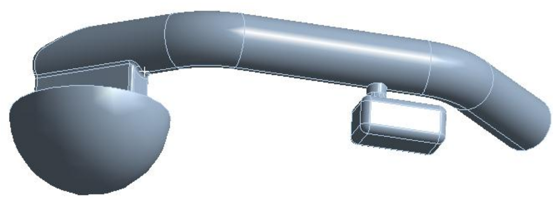
Analysis Modeling

The modelling designed for flow analysis in the present article has the dirty side in the intake system as the object as shown in Fig.1, and a resonator for intake noise reduction is mounted to the main duct for configuration. Modelling was applied to the intake system by using CATIA, and a hemisphere was modelled at the inlet to realize atmosphere. As shown in Figure 1, the number of meshes used in the test was about 470 thousand ea. and inflation mesh was used to simulate the boundary layer on inside wall of the intake system.

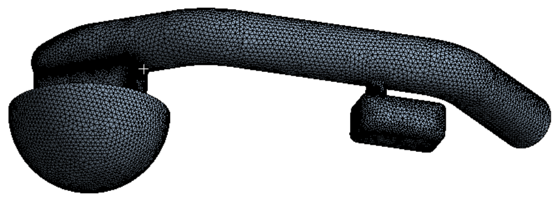
Boundary Conditions

Atmospheric pressure was set for the pressure condition to allow inflow of air into the intake system interior from the virtual atmosphere, and air intake flux at the intake system outlet and velocity boundary conditions corresponding to the flus were applied to force inflow of air into the intake system interior. By using the universal analysis program of ANSYS Fluent, an analysis was conducted for flow rates, streamline and flow noise of the intake system interior.

In order to replicate the turbulent flow by presuming that the internal flow of the air intake system is an incompressible complete turbulent flow in normal, this Study executed numerical analysis by using the realizable K-ε turbulence model provided by Fluent. The boundary conditions of the inlet, outlet and air properties in accordance with the engine rpm are given in the table 1.



(a) Intake pipe model



(b) Mesh model

Figure 4: Intake pipe model and mesh model

Table 1: Simulation boundary condition

Condition	Value
Inlet	Pressure = Atmospheric pressure
Outlet	Case1 (1,000rpm) = 42 kg/h Case2 (2,000rpm) = 87 kg/h Case3 (3,000rpm) = 140 kg/h Case4 (4,000rpm) = 207 kg/h Case5 (5,000rpm) = 264 kg/h
Air properties	Density = 1.225 kg/m3 Viscosity = 1.515x10-5 kg/m·s

Analysis Results

Figure 2 analyzes the flow of each engine according to their rpm. The flow showed identical tendencies in all engine rpms. Figure 6 shows the cross section of the intake in accordance to the flow. It was confirmed that the flow was fastest in the middle of the pipe at 18m/s. The flow moved in a widening gyre, creating a vortex. It barely changed in the straight sections.

Figure 6 shows the flow noise under 5,000rpm. 90dB of noise was emitted in the section where the duct pipe curved, and it seems that the noise results from the vortex created by the acute curve of the pipe.

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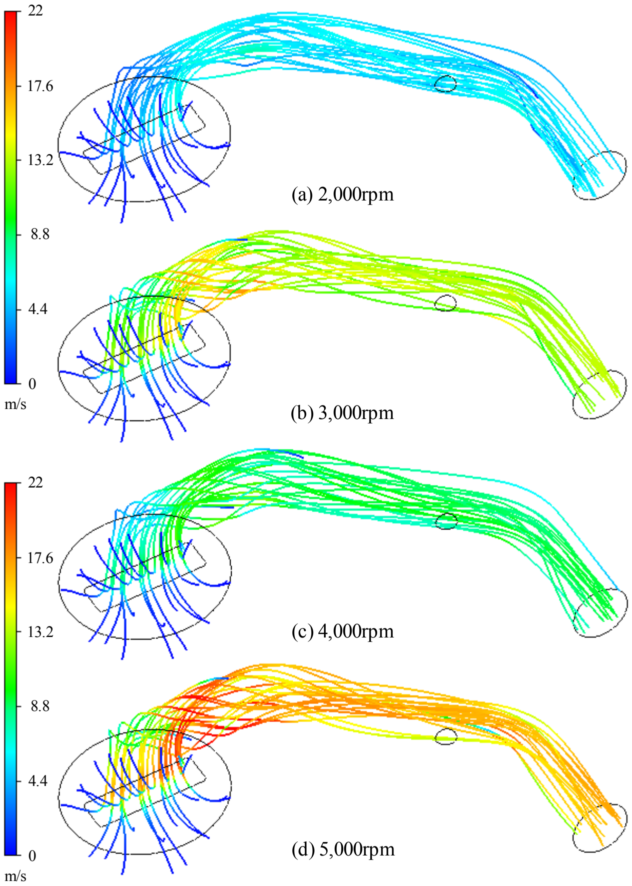

Figure 5: Velocity streamlines of each engine rpm

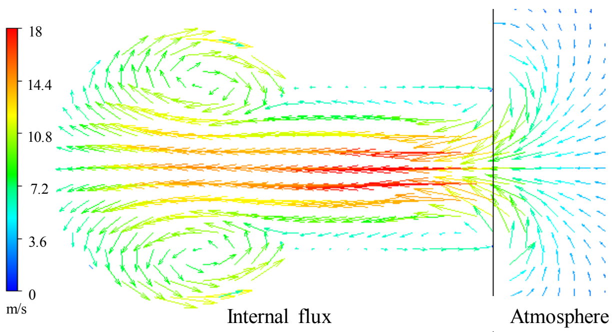

Figure 6: Internal flux of intake duck inlet at 5,000rpm

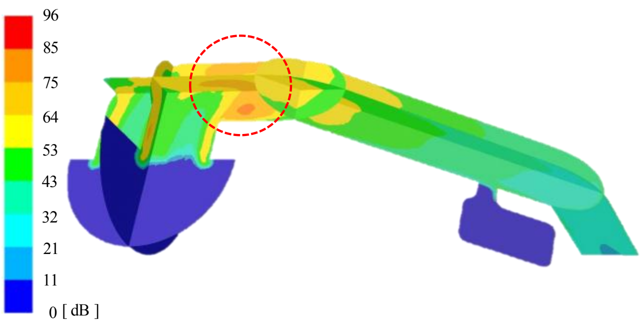

Figure 6: Internal flux of intake duck inlet at 5,000rpm

CONCLUSION

In the present study, latest studies on reduction measures for the noise produced in the contemporary engine intake system have been discussed, and the following conclusions have been obtained by analysis of flow and noise inside the intake pipe with mounting of a resonator through finite element analysis.

1) We have analyzed the current research trend on noise reduction using absorption materials, resonators, form of the compressor, and active noise control.
2) After analyzing the flow, we have confirmed that a vortex was formed near the intake, and about 90dB of flow noise was emitted under 5,000rpm.
3) Through finite element analysis, a part with relatively high noise has been discovered inside the intake pipe, which may be used for identification of optimum positions when mounting positions for a resonator are envisioned in the future.

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