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자동차 배기계에 대한 음질 향상

Improving Sound Quality of the Exhaust System Using Convolution Analysis

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Key Words : Sound Quality(음질), Exhaust System(배기계), Convolution Analysis(숭적해석)

ABSTRACT

The exhaust system could be a dominant acoustical source in the passenger's vehicle. It would be very important to obtain the acoustically good exhaust system, in order to control the cabin interior sound in automotive. In order to obtain the acoustically good exhaust system in automotive, many kinds of exhaust system should be measured, and simultaneously those results should be compared by the sound quality parameters. In this paper, in order to develop the methodology determining sound quality parameters, acoustic simulator is introduced, combining the time domain analysis and convolution analysis. As an example to verify the reliability of this method, several kinds of measurements are carried out, and the acoustically good exhaust system is selected, based on this proposed method.

1. Introduction

Typically, a car is manufactured through the following procedures, such as conceptual design, detail design, prototype, pilot test, and mass production stage. In conceptual design stage, it should be decided who is major customer, which price, how powerful, which purpose. Great deal of virtual simulations should be carried out on graphical tools. In the detail design stage, all specifications of car have been designed, and many numerical simulations should be carried out. Static and dynamic structural analysis of chassis, safety, performance, and durability should be checked at this stage. Most of items are determined in detail before making the prototype.

Limited numbers of prototype should be made in order to check the easiness of assembly. What has to be checked at the prototype are how to assemble it, interference, how to match between each functional components. After making prototype, many performance tests should be continued. Such as, NVH (Noise, Vibration and Harshness), durability, safety, emission, maneuvering, functionality.

One of the most important test items of pilot test stage is NVH test. All test items carried out at the prototype test stage should be checked at this stage. All requirements should be satisfied at this stage, and all defects should be found out at this stage. This stage is very meaningful that it is the final test stage before reaching to mass production line. On the mass production line, it is very difficult to make the characteristics of items correct.

It is also difficult to control the noise induced by the exhaust system in trouble-shooting point of view. Because the interior noise could be checked in pilot test stage and trouble-shooting is one of main activities of this stage. The general way of doing trouble-shooting to control the exhaust noise is the practical test method.

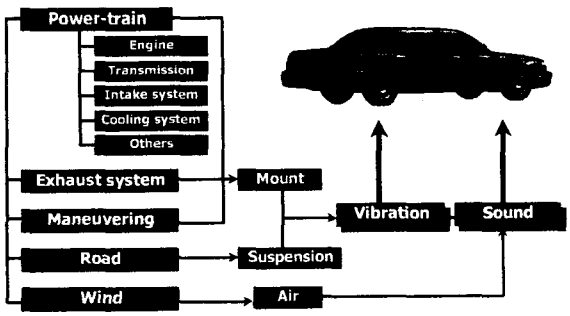

Fig. 1 Typical Noise Transfer Paths of the Passenger's Vehicle

It means the worker should repeat to assemble the exhaust system and do measurement by all through the engine loading condition.

In this paper the simulation tool to control the exhaust system noise as a trouble-shooter is proposed by using the convolution method between exhaust system and cabin of automotive. The noise induced by the exhaust system is transferred to the cabin through the several noise paths, for example, air and windows. The TRF (Time Response Function) between exhaust system and cabin is obtained by the measurement and de-convolution. Using this TRF, the cabin interior noise can

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be simulated for various noise sources. It means that if the noise characteristics of exhaust system are measured in anechoic room or test bench, the interior noise induced by the exhaust system can be estimated by using the obtained TRF.

2. The Convolution Method

The convolution of two time functions $f(t)$ and $h(t)$ is defined mathematically as,

$$g(t) = \int_{-\infty}^{\infty} f(\tau)h(t-\tau)d\tau$$

For the convenience, this is often represented symbolically as,

$$g(t) = f(t) * h(t)$$

where the star means 'convolution'.

At this case, the $f(t)$ and $g(t)$ represent the noise source induced by the exhaust system and noise receiver in cabin of automotive. The $h(t)$ represents the TRF(Time Response Function) between source and receiver shown in Fig.2.

The $f(t)$ and $g(t)$ can be obtained through the measurement by using two microphones correspondingly attached to exhaust system and cabin. Then the TRF $h(t)$, which is representing the characteristics of noise transfer from engine and cabin, could be calculated by using the de-convolution of source and receiver.

Using this calculated TRF, the estimated noise in cabin could me simulated corresponding to the various sources, which are measured in the test bench, for example, anechoic room.

$$g_i(t) = h(t) * f_i(t)$$

Where, this means the arbitrary noise in cabin $g_i(t)$ corresponding to the arbitrary noise source of engine $f_i(t)$, which can be measured on stable condition, independent from cabin, can be estimated by using the convolution method.

Actually, various noise characteristics of exhaust system could be simulated to decide the optimum or target noise in cabin.

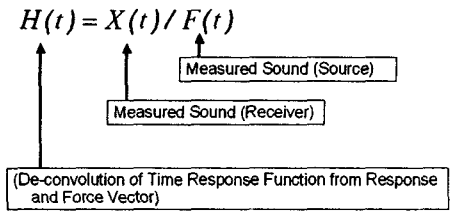

Fig. 2 The Relationship of the Convolution between Source and Receiver

3. The Experiments

In order to obtain the TRF between exhaust system and cabin noise, the noise characteristics of exhaust system and cabin are measured by experiment. The system configuration of the experiment is shown in Fig. 3. The Bruel & Kjaer HATS(Head and Torso System) is located in the cabin to obtain the cabin noise, and the other microphone is located in the outlet of exhaust system. The sounds of exhaust system and cabin can be obtained and analyzed in both time and frequency domains by Bruel & Kjaer Portable PULSE. The PULSE Bridge to MATLAB can transfer the measured and analyzed data from PULSE to MATLAB. Actually, the TRF is calculated in MATLAB using the transferred data. The way how to extract the TRF using the measured signals is shown in Fig.2. All the process to simulate the signal from the measurement is shown in this figure.

Using the obtained TRF, the simulation to develop the acoustically good exhaust system is carried out. After applying some acoustic treatments in exhaust system, the sound characteristics of exhaust system are measured in the test bench. If the sound characteristics of the exhaust system itself are applied to the TRF, then the simulated cabin sounds are generated using the convolution analysis referring to Fig. 4.

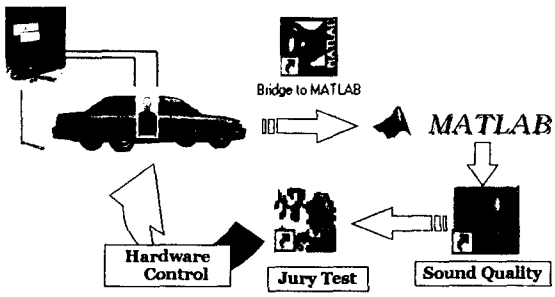

Fig. 3 Test and Simulation Procedure of Vehicle Interior Noise

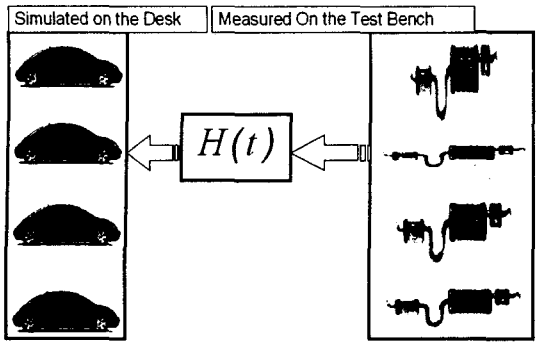

Fig. 4 The Function of the Simulated TRF(Time Response Function)

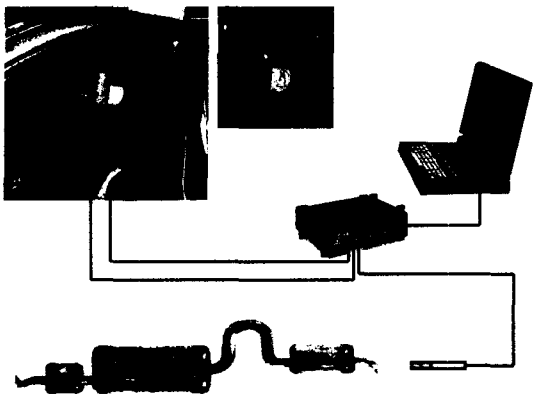

Fig. 5 The Experimental Set-up

For this experiment, the sounds in the cabin are measured using the HATS under the operating conditions. The cabin sound is represented in the left ear position of the passenger's front seat. On the other hand, the exhaust system sound is measured in the outlet of the muffler.

Fig. 5 shows the experimental set-up.

4. Concluding Remarks

The developed effects are shown in Fig. 6 and Fig. 7 comparing with the original and modified sound quality index, Loudness. According to the obtained results from experiments and calculations, using Bruel & Kjaer PULSE and MATLAB, it could be said that there are many possibilities to use this simulation process in developing and trouble-shooting NVH of automotive, because it could save working time and omit much assembling works. To improve the NVH testing technology, the following items are proposed to apply the proposed simulation technology in this paper.

- To define the optimum exhaust system NVH to chassis
- For trouble-shooting tool of rattle vibration
- Identification of noise source of automotive
- Noise source classification and contribution

Using the proposed simulation technique, the noise signal could be converted into the .WAV file formation in personal computer, which could be checked on the objective test by the audience in order to make a target sound.

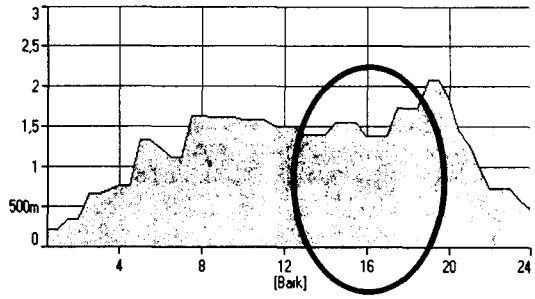

Fig. 6 Loudness of Cabin (Passenger's Left Ear, Original)

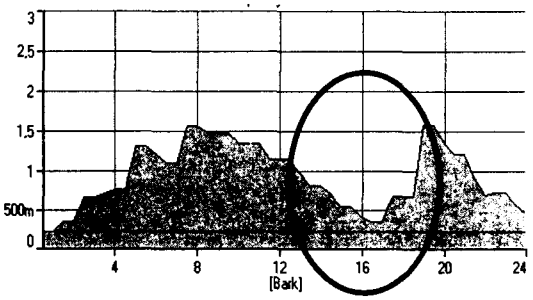

Fig. 7 Loudness of Cabin (Passenger's Left Ear, Developed)

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