inter.noise 2000

The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

A TROUBLE-SHOOTING PROCEDURE OF VEHICLE INTERIOR NOISE USING CONVOLUTION METHOD

Y. Ryu

Bruel & Kjaer, Skodsborgvej 307, 2850, Naerum, Denmark

Tel.: +45 77 41 23 87 / Fax: +45 45 80 14 05 / Email: ysryu@bk.dk

ABSTRACT
There could be many causes to occur the unpleasant noise Automotive. Major noise source of Automotive is the engine, and it is very difficult to reduce the noise, because it has strong relation with the engine power. Hard-to-handle and time-consuming to work could be another obstacles to reduce the noise from engine, as a trouble-shooting. It is very hard and time-consuming work to disassemble the engine from body and re-assemble it. In this paper, in order to make the trouble-shooting activities efficient the convolution method is suggested. Getting the TRF (Time Response Function) between the source and receiver, the estimated response of receiver could be calculated using the obtained TRF, according to the new source. The theoretical background is described and experiment for verification is performed.

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, manœuvring, 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 correct the characteristics of items.
The noise induced by the engine is very difficult to control 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 engine noise is the practical test method. It means the worker should repeat to assemble the engine and do measurement by all through the engine condition.
In this paper the simulation tool to control the engine noise as a trouble-shooter is proposed by using the convolution method between engine and interior of automotive. The noise induced by the engine is transferred to the cabin through the noise path, for example, air and windows. The TRF (Time Response Function) between engine and cabin is obtained by the measurement and deconvolution. Using this TRF, the cabin interior noise can be simulated for various noise sources. It means that if the noise characteristics of engine are measured in anechoic room or test bench, the interior noise induced by the engine can be estimated by using the obtained TRF.

2 - 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 convenience, this is often represented symbolically as,

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

where the star means 'convolution'.

At this case, $h(t)$ and $g(t)$ represent the noise source induced by the engine and noise receiver in cabin of automotive. $h(t)$ represents the TRF (Time Response Function) between source and receiver shown in Fig. 1. In Fig. 2 the principal of convolution is shown.
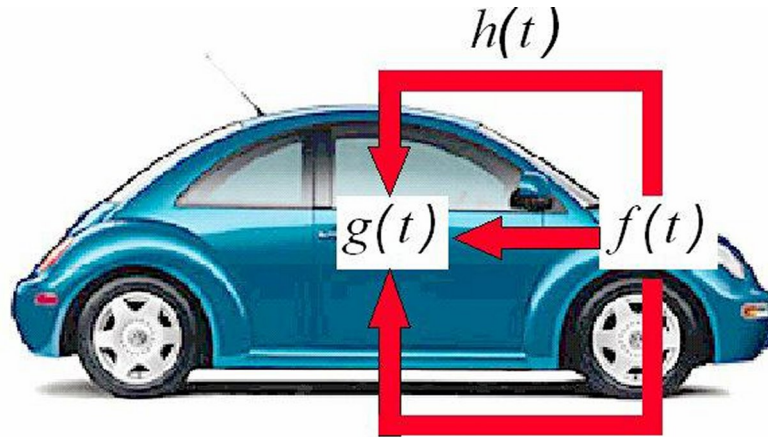

Figure 1: Noise transfer path between exhaust system and cabin.
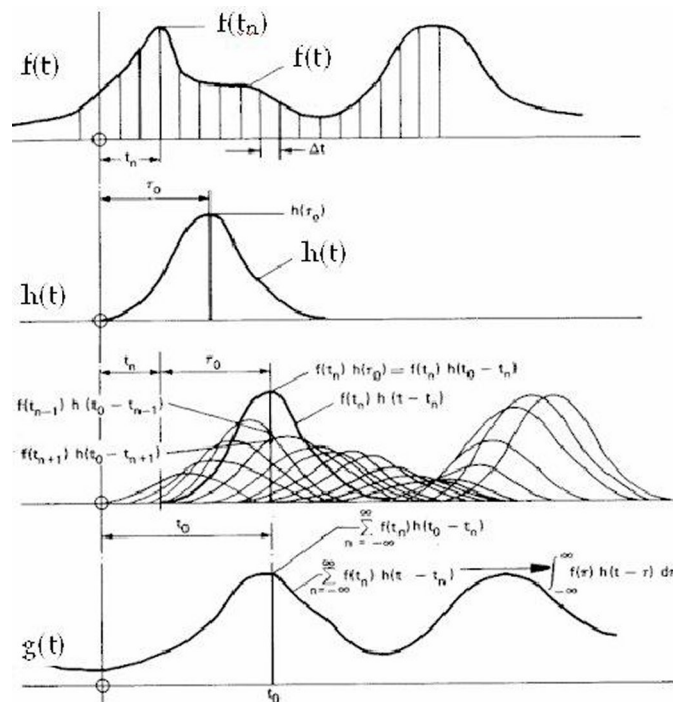

Figure 2: Convolution of two time functions.

$f(t)$ and $g(t)$ can be obtained through the measurement by using two microphones correspondingly attached to engine 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 deconvolution 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.

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

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.

3 - EXPERIMENT
In order to obtain the TRF between engine and cabin noise, the noise characteristics of engine 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 engine. Bruel & Kjaer Portable PULSE can obtain both signals and analyze it at a time and frequency domain. Using the PULSE Bridge to MATLAB the time signals are transferred to MATLAB, and the TRF is calculated in MATLAB. The TRF can be calculated on deconvoluting the engine and cabin noise, measured by the PULSE. All the process to simulate the signal from the measurement is shown in this figure.
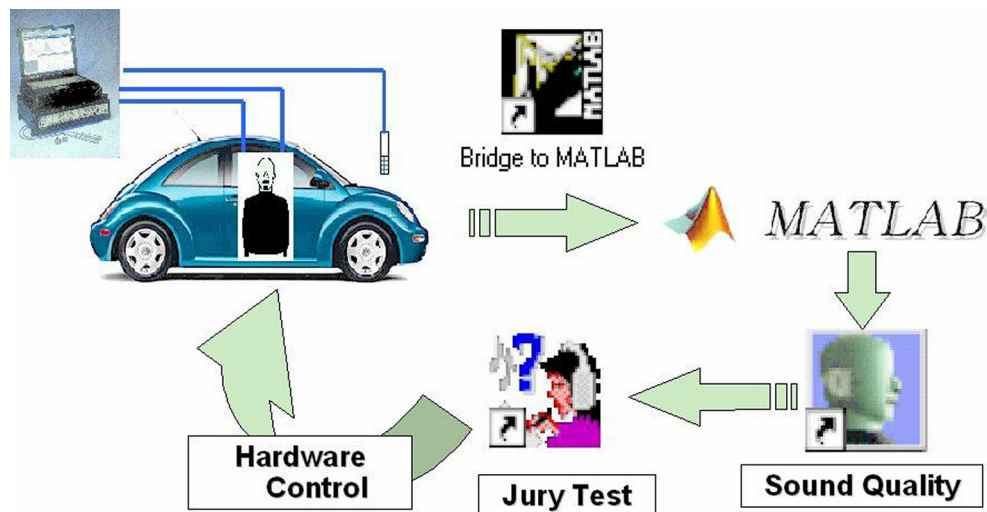

**Figure 3:** Whole process from the measurement to simulation.

The measured noises of cabin $g_c(t)$ and engine $f_e(t)$ are shown in Fig. 4. In Fig. 4a, the time signals are measured by HAT, and regenerated by Sound Quality Software of Bruel & Kjaer. Using Time Capture function of PULSE, the time signals are measured at the time domain. The PULSE Bridge to MATLAB transfers these signals to MATLAB as a UFF (Universal File Format) file. The calculated TRF $h(t)$ between these two signals is shown in Fig. 5.
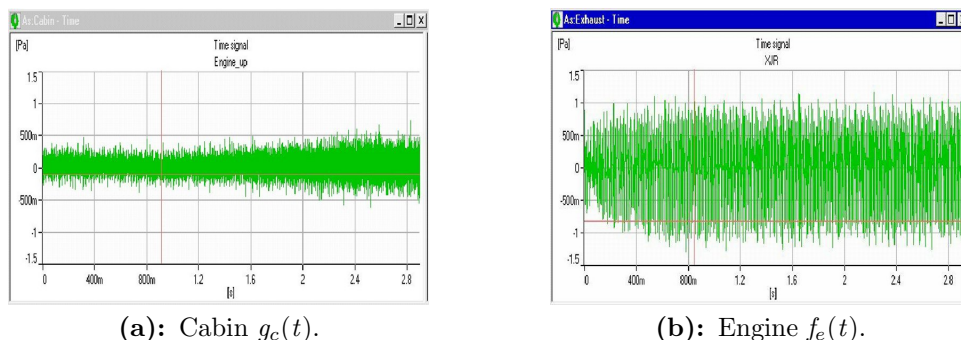

(a): Cabin $g_c(t)$. **(b):** Engine $f_e(t)$.
Figure 4: Time signals of cabin and engine.
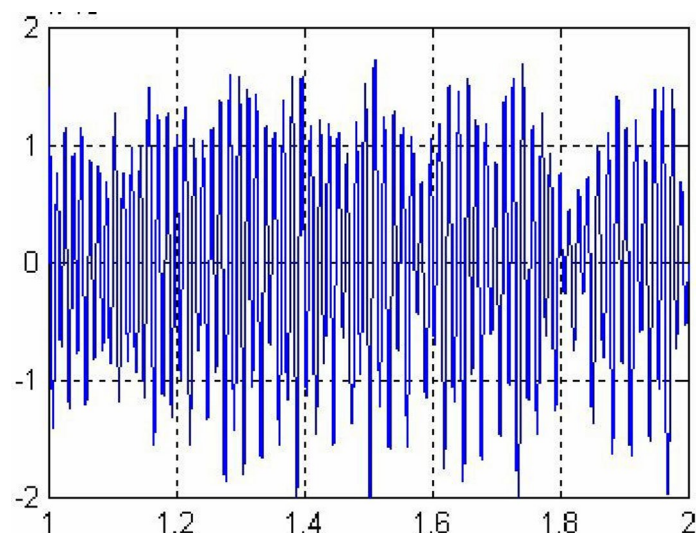
Figure 5: Calculated TRF (Time Response Function) $h(t)$ between cabin and engine.

In order to verify the process, the other exhaust $f_{er}(t)$ and cabin $g_{cr}(t)$ noises are measured during engine run-up. The measured engine noise is shown in Fig. 6. After operating the obtained TRF $h(t)$ and the measured exhaust noise $f_{er}(t)$, the estimated cabin noise $g(t)$ is obtained in MATLAB. The estimated cabin noise and measured cabin noise are compared in Fig. 7.
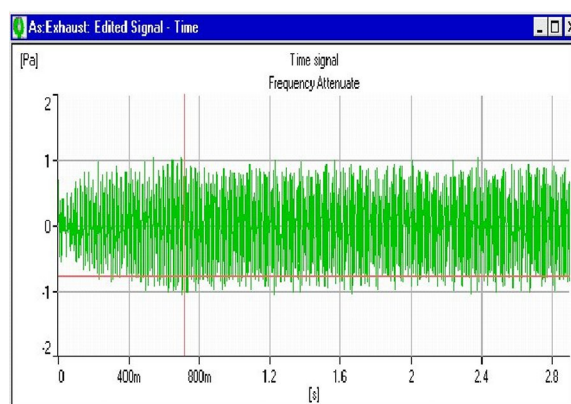

Figure 6: Modified time signal of engine $f_{er}(t)$.

4 - DISCUSSIONS

According to the obtained results from experiment and calculation, 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 engine 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.
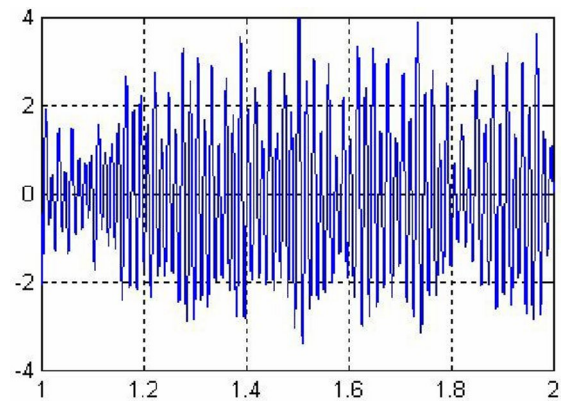
Figure 7: Simulated time signal of cabin $g(t)$.

REFERENCES

1. **R.B. Randall, B. Tech**, *Frequency Analysis*, Brüel & Kjær, 1987

2. **J.R. Hassall, K. Zaveri**, *Acoustic Noise Measurement*, Brüel & Kjær, 1988

3. PULSE Multi-analyzer User's Manual, *Brüel & Kjær*, 1977

4. **Cyril M. Harris, Charlse E. Crede**, *Shock and Vibration Handbook*, McGraw-Hill, 1976