The omni-directional sound source analysis for evaluating the vehicle sound insulation performance

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ABSTRACT

In this paper, the measurement system using the microphone array developed for analyzing cabin noise of the vehicle and its applications are discussed. The sensor is a three dimensional microphone array, the microphones and cameras are equipped on the rigid sphere. The cameras are used for acoustic visualization. As applications, the experiments in both reverberation chamber and anechoic chamber are discussed. These results show that this system is very useful to evaluate or improve the vehicle sound insulation performance.

1. Introduction

It becomes popular to use the microphone array based measurement system for noise control engineering. Such system has a lot of advantages. For example, the microphone array based system can obtain rich information compared with the single microphone measurement. Also, it becomes easy to analyze the transient or non-stationary noise phenomena. On the other hand, it may become non-user-friendly measurement system. For example, it takes a lot of time to setup the system, the calibration procedure becomes complicated, and so on.

In this paper, the sensor and analysis system which are designed for improvement of vehicle cabin noise are introduced [1], [2]. And the applications for visualization and reducing the cabin noise in a vehicle are discussed. To use such system for noise control engineering, it is also important to obtain the result in short time. This system is using the cameras and they help to improve of the user-friendliness and rapid measurement.

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2. Omni-directional sound source analysis system

The sensor of this system is shown in Fig. 1. We call this sensor "Sphere-Baffled Microphone array (SBM)". The sensor is a sphere shaped and thirty-one microphones and twelve cameras are equipped on an aluminum ball surface. About size of the sensor, the diameters of 0.26m, 0.2m and 0.165m are available. These sensors are applicable for different frequency range. The arrangement of the microphones and cameras is also shown in Fig. 1.


Fig. 1 Sphere-Baffled Microphone Array (SBM)

The reason why we design this microphone array as spherical shaped is that we want to realize the "omni-directional" sound source identification with this sensor, having uniform directivity for any direction around the sensor. The microphones are arranged on the basis of the dodecahedral and icosahedral objects' vertexes, but the number of the microphone is thirty one. The one microphone is reduced from original design on account of the interference with the "neck" of the sensor without losing its performance.

With using the exact solution for the sphere diffraction of sound wave which is composed from the sum of spherical harmonics, it is easily possible to calculate the sound pressure distribution on the rigid sphere by computer simulation[3]. On the contrary, if sound pressure information also including both amplitude and phase on the surface of the sphere are measured at several points, it is possible to estimate the characteristics of the sound sources around the sphere as an inverse problem. In this system, all the information acquired at thirty one microphones is used and taking the rigid sphere effect into the account, the sound source information around the sphere is analyzed by beamforming (BF) method.

About the twelve cameras equipped on the sphere, there are two objectives. The first objective is to superimpose the calculated results into the pictures. The "hot spot" is determined easily on the pictures taken by camera. Fig. 2 shows the results both with and without photo. Usually the result measured with microphone array is shown as a contour map. If the sound source information is superimposed into the photos, it is very easy to identify where the hot spot is. The second objective is to provide great efficiency for the experiment work. This system contains twelve cameras, and there is no dead spot around the sphere. In addition, the optimum arrangement of the microphones helps to analyze the sound sources at any directions with uniform directivity. Thanks to these earmarks, it is not required to pay great attention to the settings, such as angle of the sensor, and so on. It is a great advantage for the measurement within limited time.

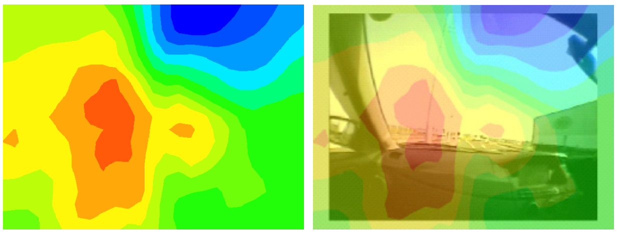

Fig. 2 Estimated sound source image (Left: without photo, Right: with photo)

3. Analysis for evaluating the vehicle sound insulation performance

Among the noise phenomena of vehicle, we focused on the phenomena related to the air-borne noise in the cabin. Typical source of air-borne noise in vehicle cabin are as follows.

- Engine
- Intake / Exhaust
- Tire
- Wind

The model experiments using the loudspeaker were conducted to visualize the sound insulation effect.

In this paper, the vehicle sound insulation performance is classified into two categories. The first one is called "comprehensive sound insulation performance", which is not focused on any special sound sources. The second one is called "partial sound insulation performance", which is focused on specific sound source or transfer path.

To evaluate the "comprehensive sound insulation performance", the vehicle was set at the reverberation chamber and excited acoustically from outside of the vehicle. The evaluation point was set inside of the vehicle cabin. The reverberation chamber is simulating the diffused sound field and sound pressure level distribution in the reverberation chamber is almost uniform. In this case, it is easy to find the sound insulation "hot spot" of the vehicle from the measurement inside of the cabin.

To evaluate the "partial sound insulation performance", the experiment in hemi-anechoic chamber was conducted. As the sound source, the loudspeaker was used and set at the certain position which is related to the actual sound source.

The reason why the loudspeaker was used instead of the actual noise source is the repeatability of the measurement is the most important issues. Also, with the loudspeaker measurement, the signal to noise ratio at the measurement can be much better, compared with the real situation. For the evaluation focused on the airborne component of the noise, the loudspeaker experiment is very useful.

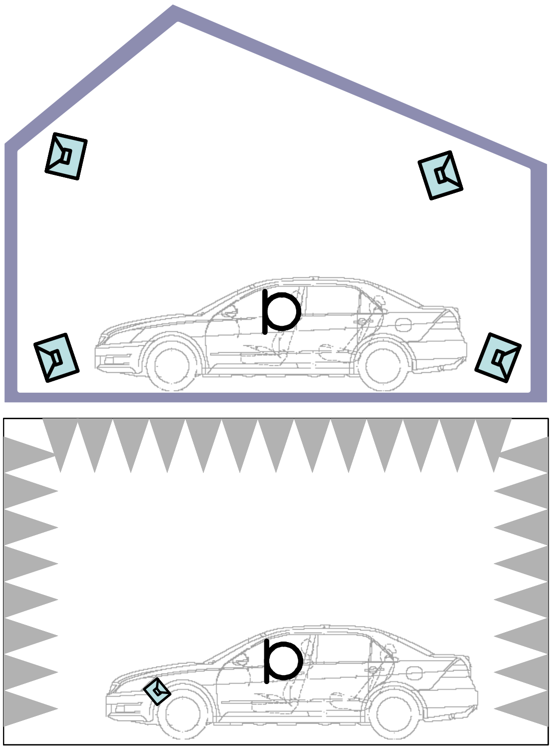

Fig. 3 Two measurement setups for evaluating vehicle sound insulation performance
(Top: for “comprehensive sound insulation performance” Bottom: for “partial sound insulation performance”)

3.1 Experiments in Reverberation Chamber

The measurement for evaluating “comprehensive sound insulation performance” was conducted as follows. The vehicle was set at the reverberation chamber. The dimension of the reverberation chamber and measurement condition is as follows.

- Volume : 140 m^3
- Source (loudspeaker) : 4 channel
- Excitation condition: pink noise (incoherent noise from each four channels)
- Analysis condition: from 200Hz to 5000Hz, with 1/3 octave bands

The sensor, SBM, was set at the driver's seat. By this setting, the most significant place of the sound insulation for driver's ear position is expected to be measured.

The result is shown in Fig. 4. The limitation of the amount of the proceedings, the results are limited to 250Hz, 2000Hz and 4000Hz. At low frequencies, at 250Hz, the contribution from the ceiling (or headliner) is dominant. On the other hand, at 2000Hz, the A-pillar, the place in between the instrument panel and front glass, and rear glass are dominant source. Furthermore, at 4000Hz, the contribution from the B-pillar is most significant, also the contribution from the A-pillar at passenger side is observed. With this method, it is possible to visualize the significant sound sources at various frequencies from the one-shot measurement.

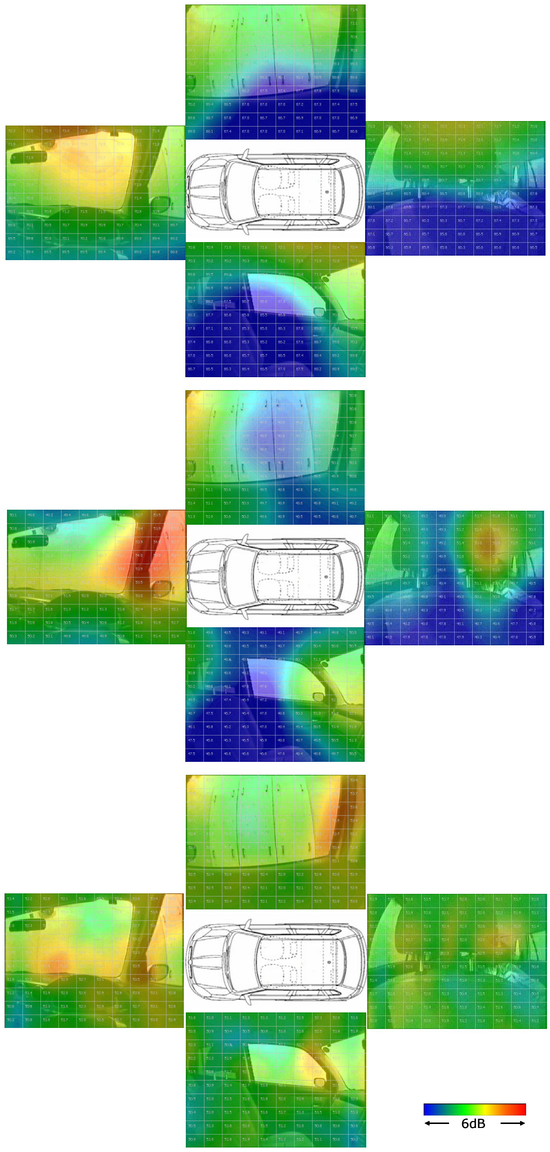

Fig. 4 Results in reverberation chamber
(From top, 250Hz, 2000Hz and 4000Hz)

3.2 Experiments in Hemi-Anechoic Chamber

Next, an experiment in hemi-anechoic chamber was conducted. The same vehicle used in reverberation chamber measurement was used and the experiment was focused for the airborne noise component from engine.

As a sound source, a loudspeaker with hose shaped nozzle was used. The position of the source was set to backward of the engine, as Fig. 5. The SBM sensor was set at the driver's seat.

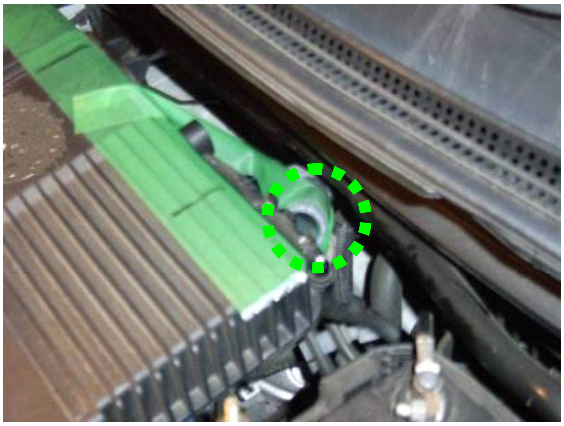

Fig. 5 Hose-shaped sound source by the engine

To select the test conditions, the result at the reverberation chamber was taken into the account. Three measurement conditions were selected and tested as below.

1) Baseline
2) Plan A (The felt was filled at the gap between the instrument panel and the front glass.)
3) Plan A + Plan B (Plan A + The felt and rubber sheet was set at the step of the driver's sheet.)

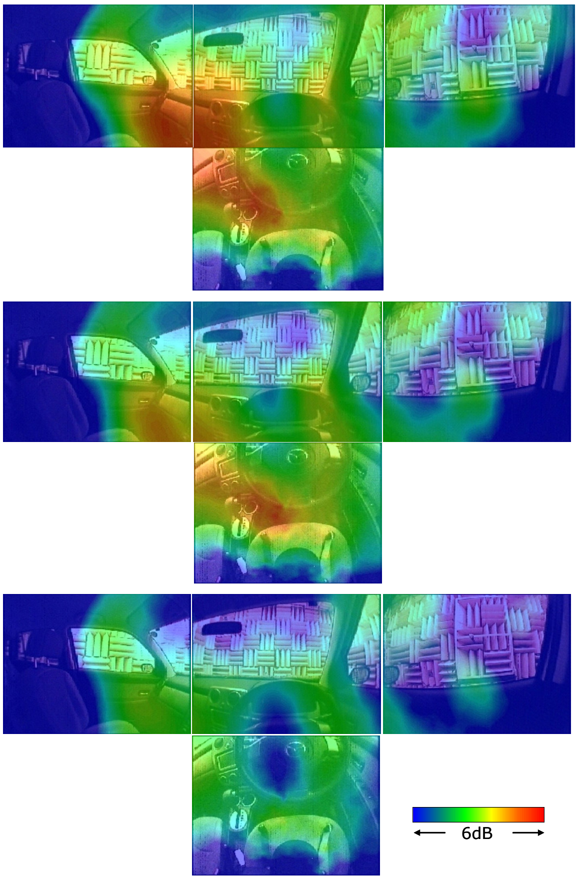

Fig. 6 Results at 800Hz (From top, Baseline, Plan A and Plan A + Plan B)

The results are shown in Fig. 6 and Fig. 7. They are the results at 800Hz and 4000Hz, respectively. At 800Hz, the significant reduction of the noise can be achieved by Plan A. At 4000Hz, the plan B will be great improvement compared with plan A.

The SPL improvement at the driver's ear position was shown in Fig. 8. In this figure, at 800Hz, the Plan A may be the best counter plan for reducing such noise. On the other hand, at high frequencies, the Plan B may be the best one to reduce such noise.

From these results, it is very important to make an adequate noise control taking its performance, frequency characteristics of actual noise source, etc. into account. This system can help to make it.

The conventional method requires rough knowledge of sound source information before conducting the experiments. On the other hand, this method requires no such information beforehand. It is very quick.

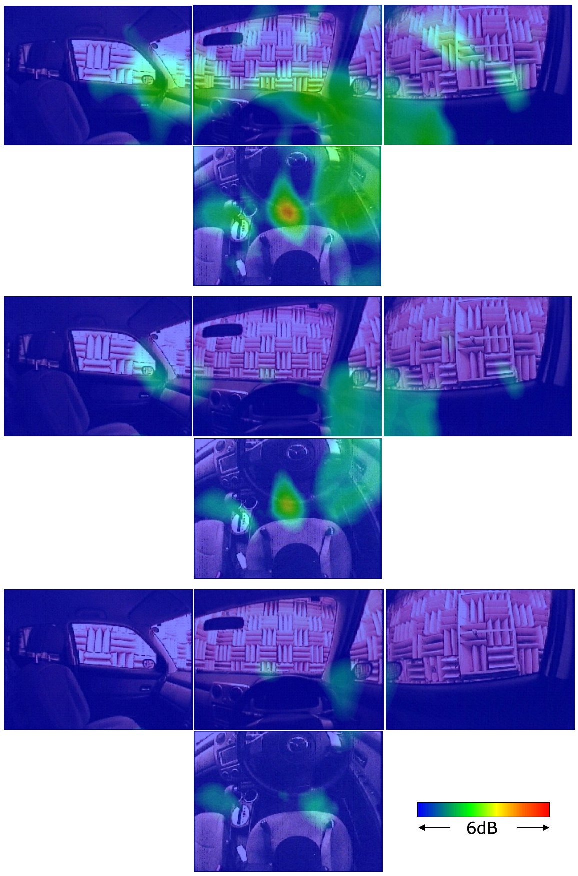

Fig. 7 Results at 4000Hz (From top, Baseline, Plan A and Plan A + Plan B)

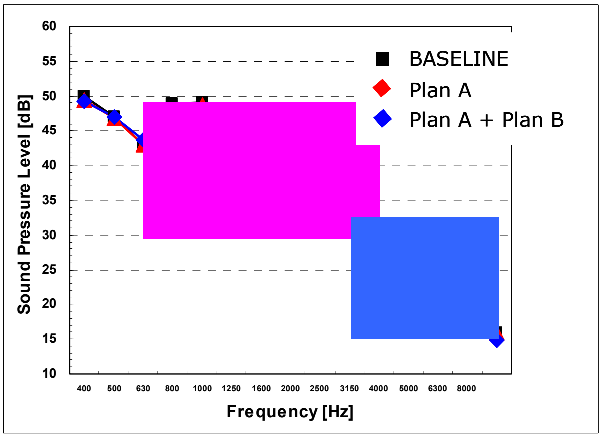

Fig. 8 Frequency characteristics of SPL at each stage

4. Concluding Remarks

The omni-directional sound source identification system with SBM was introduced and some experiments for improving the automotive sound insulation performance are presented. This system was developed from the idea of the real engineer who is working for automotive industries. To visualize the sound information, the cameras are equipped on the surface of the sphere and the calculated sound source information is superimposed into the photo. The enormous information can be presented to the engineer. According with increasing the requirements for the measurement, we keep on developing the much useful measurement system.

Finally, we have started to apply this measurement technique for the room acoustics field [4], [5], [6].

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