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ON THE USE OF THE SOUND INTENSITY METHOD FOR DETECTING NOISE SOURCES NEAR THE REFLECTING PLANES

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ABSTRACT

The problems in the identification and localization of noise sources using the sound intensity method are dealt with for the reactive field. For these purposes, a three-dimensional model structure resembling the engine room of the passenger car is considered. The model contains complicated noise sources distributed within the small space, which includes the narrow, connected, reflecting planes constructed with rigid boxes. In addition, a small clearance exists between the structure and the reflecting bottom. The sources are actually hanging in the space over this rigid bottom. For this model, the near field acoustic intensity is calculated scanning over the upper plane opposite to the bottom by using the acoustic boundary element method. The effects of relative source phases, frequencies, and locations are investigated. It is observed that the application of sound intensity method without proper care in this situation can yield the detection of fake sources. Therefore, the sound intensity scanning over the engine room upper, with its hood open, may indicate the false positions or components as noise sources. The field reactivity has to be checked and the care should be attended in this type of measurement using the sound intensity methods.

INTRODUCTION

The sound intensity is important for identifying the sound sources and for measuring the radiated sound power from source. Many researchers have been tried to use the sound intensity for source detection during the several decades. Expression formats of contour map or vector plot for measured or calculated intensity have been considered very useful in understanding the sound radiation and propagation characteristics from the source and at the field. Especially, the vector quantity of sound intensity that represents the acoustic energy flow is very attractive for noise source identification and ranking purpose. Many researchers and engineers applied this method to various noise problems and examples include cars, aircraft, machine, tools, heavy machinery, engines, etc, notwithstanding the fact that the results are field values instead of the source properties. It is often observed that NVH engineers in car manufacturers and some in academia present the results of sound intensity scanned over the engine room upper surface after detaching the bonnet. After constructing vectorial or contour maps, they usually claim that the parts of engine or engine accessories just below the high spots of active and/or reactive intensity patterns as major sources. However, the engine room is a highly reactive field constructed with narrow channels between chassis, engine, transmission, exhaust pipes, air inlet ducts, coolant radiator, *etc.* and there is the sound reflection from the engine undercover and/or ground surface. Especially, engine rooms in modern cars are tending to be more and more compact with various accessories. In these small spaces comprised of narrow channels and small irregular cavities, sound field is very complicated due to the high interaction of the waves in the field and intense standing waves can be generated. If the scanning surface of the intensity is in the near field, the sound field will be also very complicated. This fact makes the problem very hard to understand and the source identification becomes very difficult job.

In this paper, the possibility of source identification by using the sound intensity measurement in the highly reactive field is studied. As an example radiator structure, a complicated layout of the partially enclosed radiators as a simplification of the car engine room is dealt with and the model is constructed with several boxes containing the correlated noise sources. The variation of active and reactive intensity pattern on an upper field plane is analyzed varying the frequency and the relative phases of sources. First, The measured intensity results are compared with the theoretical result by using the boundary element method (BEM). After confirming the accuracy of the analysis result by the BEM, effects of the variation of aforementioned parameters is analyzed next by using the BEM.

SOUND INTENSIMETRY

Active sound intensity, ***I***, and reactive sound intensity, ***Q***, at a point in a given direction r can be given by

$$I(r)=\tfrac{1}{2}\mathrm{Re}\{P(r)\,U^*(r)\},\qquad Q(r)=\tfrac{1}{2}\mathrm{Im}\{P(r)\,U^*(r)\},\tag{1}$$

where $p(r,t)=P(r)\exp(i\omega t)$ is the acoustic pressure, $u(r,t)=U(r)\exp(i\omega t)$ is the particle velocity in the r-direction, and $U^*(r)$ denotes the conjugate of $U(r)$.

If the sound pressures are measured at two microphones separated by Δr in the r-direction, the mean sound pressure and particle velocity at the midpoint can be expressed approximately as follows:

$$p(t)=\frac{p_1(t)+p_2(t)}{2},\quad u(t)=-\frac{p_2(t)-p_1(t)}{i\rho\omega\Delta r}.\tag{2}$$

By using the Fourier transform, sound intensity values can be obtained as

$$I_r(\omega)=-\frac{\mathrm{Im}\{G_{12}(\omega)\}}{\rho\omega\Delta r},\qquad Q_r(\omega)=\frac{1}{2\rho\omega\Delta r}[G_{11}(\omega)-G_{22}(\omega)],\tag{3}$$

where G_{ij} means the cross spectrum between p_i and p_j. [1]

MODELING AND MEASUREMENT METHOD

As a test example, a simplified engine room of the passenger car is taken and the model is comprised of 4 rigid cubic boxes different in size. These boxes are surrounded by an enclosure open in upper and lower planes and the lower opening has very small clearance from the rigid reflecting ground as shown in Fig.1. Each box has one or two loudspeakers as sound sources. It is resumed that highly reactive fields are generated between boxes, outer case and ground plane. The internal boxes were made of the acrylic plate with 15 *mm* in thickness and the interior cavity of each box was packed with the sound absorbing material to suppress the unintended resonances of interior spaces of boxes.

Three dimensional sound intensity and mean sound pressure were measured at the evenly spaced 165 points on the field plane located 35 *mm* above the highest edge of the model (385 *mm* in elevation measured from the reflecting ground plane. See Fig.1.(b)). Measurement was carried out on the rigid baffle in the anechoic chamber. The sound intensity probe (B&K 3520) with 12 *mm* microphone spacer (frequency range = 125 Hz – 5 kHz) and the real-time frequency analyzer (B&K 2144) were used. Data were collected through 1/24-octave band filter. Loudspeakers were excited by the white noise fed from a signal generator for obtaining the correlated source signal.

The boundary element model of the structure consisted of 1152 nodes and 572 quadratic elements as depicted in Fig.2. The maximum characteristic length of an element was 177 *mm* which limits the applicable high frequency to 650 Hz when the characteristic length corresponds to $\lambda/3$ (maximum modeling error $\cong$ 1%). The frequency range of interest was 200~650 Hz.

Measurements and simulations were done for the different phase conditions of the sound sources as summarized in Table 1.

Table 1. Loudspeaker phase settings for measurements and simulations.

Set number	Phases of loudspeakers in each box			
	Box 1	Box 2	Box 3	Box 4
1	0°	0°	0°	0°
2	0°	180°	0°	0°
3	0°	0°	180°	0°
4	0°	+45°	-45°	0°
5	0°	-45°	+45°	0°

RESULTS AND DISCUSSION

Measured sound intensity spectra on the field plane for sets 1-3 are plotted in Fig.3. Since the sound intensity was measured in the evenly spaced array, this figure has same trend with the spectra of the total sound power emitted from the measurement field plane. Major peaks are at 303, 428, 508, and 630 Hz. From the numerical simulations, it is found that these correspond to the resonances in the narrow spaces between the boxes and the reflecting planes. One can find that the mean intensity spectrum for set 1 differs from other two sets, which signifies that the phase distribution of source velocity is important in constructing the sound field as well as the geometrical complexity.

The measured vector plots of active intensity on the field plane at 508 Hz are compared with the calculation results in Figs.4-5 for the phase condition sets 1-3. It is observed that the simulated acoustic fields match well with the measured ones in the viewpoint of the location and direction of the vortices which assures the accuracy of the BEM result in this near field.

Numerical simulation was performed for 450 Hz to sets 4-5 and 1, that corresponds with 428 Hz mode in the measurement. Figs.6 and 7 show the active intensities on the measurement field plane. Locations of source-like peaks are changing with the change of source phase combination. This is due to the interaction of several sound waves from the various loudspeakers. The geometric shifts of peaks are nearly equal to $\lambda/8$ which corresponds with the phase difference of 45°. By comparing with the real source positions, it is impossible to find the correct source position from these results. In Fig.8, calculated reactive intensity vectors for the same frequency and phase setting conditions are plotted. Reactivity intensity depends on the gradient of the potential energy, that the distribution can be an assistant tool for detecting the source location. However, this measure can not indicate the true source locations in the highly reactive fields. The reactive intensity should have the same form with the distributions of sound pressure level. Fig.9 shows that source-like positions of reactive intensity results coincide with the pressure maxima and that the pressure minima are moved to the sink-like zones of reactive intensity as expected. Reactive intensity in this case is the indicator of standing waves rather than the source detector.

Reactivity index level (L_K) is one indicator of the field reactivity. L_K is defined as L_I - L_P, where L_I is the sound intensity level and L_P is the sound pressure level.[2] L_K can be affected by many parameters such as the reactivity of the field, the phase mismatch of microphones and instruments, and the phase errors included in the measurement. However, for phase-matched measurement systems, L_K can be employed as a quick and qualitative guide to evaluate whether the sound field is too much reactive or not. It is reported that L_K amounts to about 5 dB(A) in the strongly absorbed field and 12-23 dB(A) in the reactive fields.[3] Other study results show that L_K is 0.2-0.5 dB in the free sound field and 6-8.4 dB in the reactive field.[4] L_K distributions of this box model are shown in Fig.10. Most of areas in the field, L_K is less than –5 dB, that the measurement field is reactive and this field reactivity can induce the wrong detection of source.

CONCLUSIONS

Sound intensity was studied in the reactive field constructed with complicated geometry and source phases. The tested geometry of the structure resembled the engine room of the passenger car with great simplifications but retaining its basic characteristics though. Active and reactivity intensities were analyzed as the source detecting parameters by using the BEM, but both parameters could not detect the true source locations. Standing waves and interactions of waves from the several correlated sources generated the complicate acoustic field associated with the highly reactive spaces. Reactivity index was calculated on the field plane and provided the helpful information on the field reactivity.

The results of this study illustrates that the information on the source deduced from the active and reactive intensities is not true in the reverberant nearfield such as the engine room upper. In this reactive field, sound waves from several correlated sources are highly interacting with each other and one can detect only "ghost" or fake sources, especially at low frequencies.

Therefore the field reactivity should be checked before the analysis and the care should be taken in this type of measurement for avoiding or reducing the reactivity.

REFERENCES

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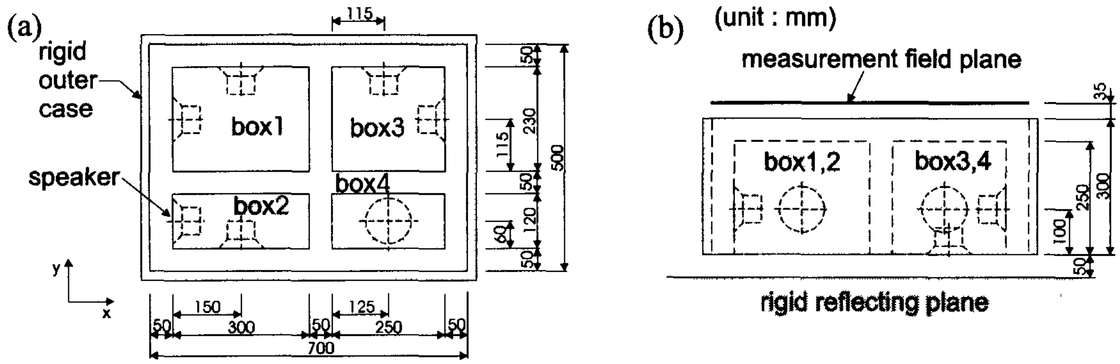

Fig.1. Test model: (a) top view, (b) front view.

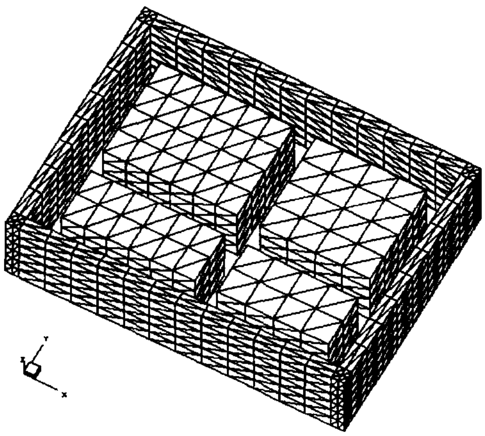

Fig.2. Boundary element model (1152 nodes, 572 elements).

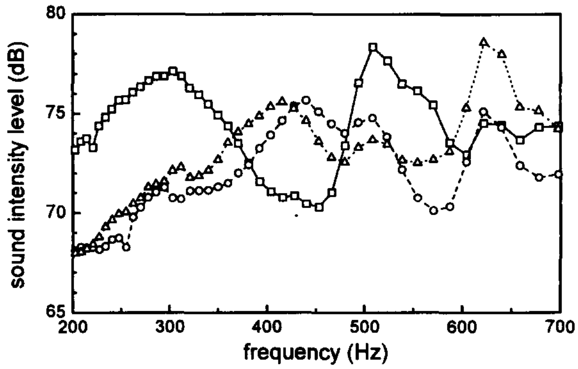

Fig.3. Measured average sound intensity level on the measurement field plane varying the source phases; --□-- , set 1; --○-- , set 2; --△-- , set 3.

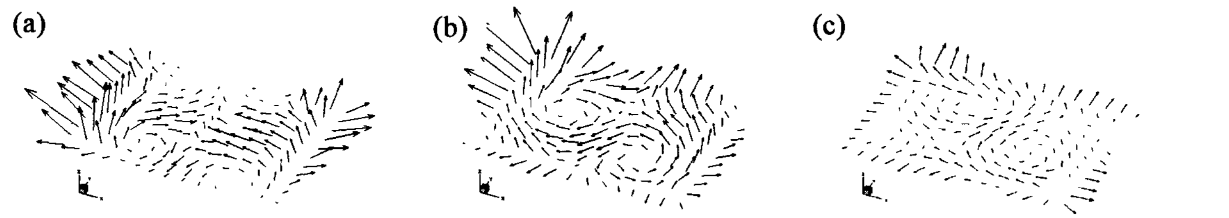

Fig.4. Measured active sound intensity vectors on the measurement field plane at 508 Hz. (a) set 1, (b) set 2, (c) set 3.

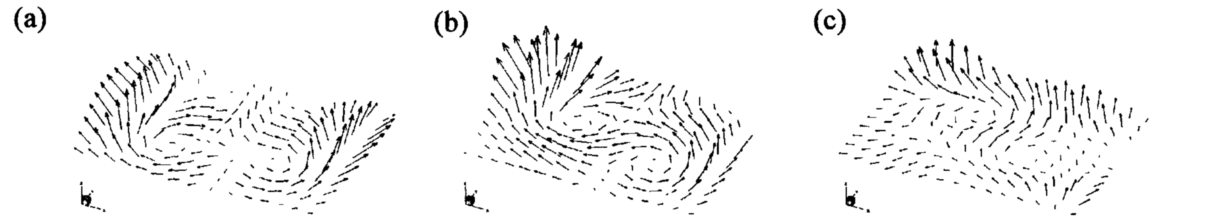

Fig.5. Calculated active sound intensity vectors on the measurement field plane at 508 Hz. (a) set 1, (b) set 2, (c) set 3.

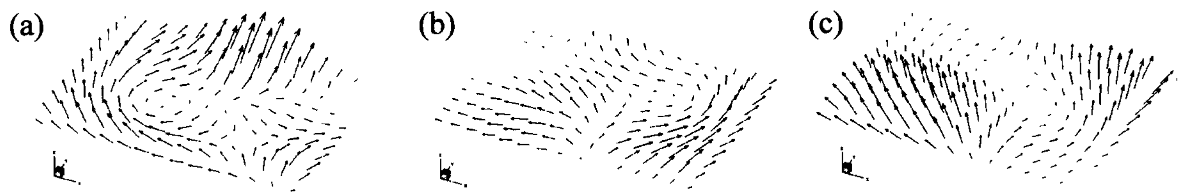

Fig.6. 3-D vector plots for active intensity calculated on the measurement field plane at 450 Hz. (a) set 4, (b) set 1, (c) set 5.

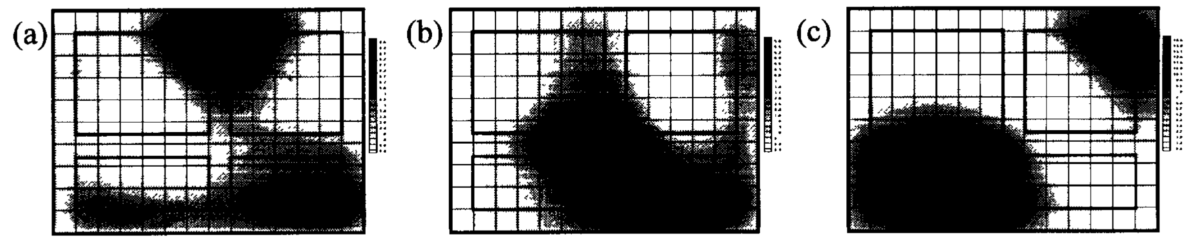

Fig.7. Calculated active intensity on the measurement field plane in the z-direction at 450 Hz. (a) set 4, (b) set 1, (c) set 5.

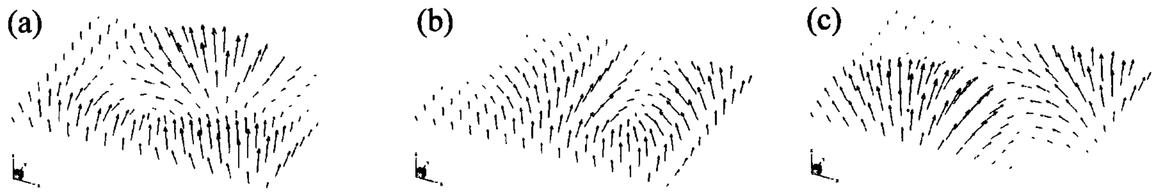

Fig.8. 3-D vector plots for reactive intensity calculated on the measurement field plane at 450 Hz. (a) set 4, (b) set 1, (c) set 5.

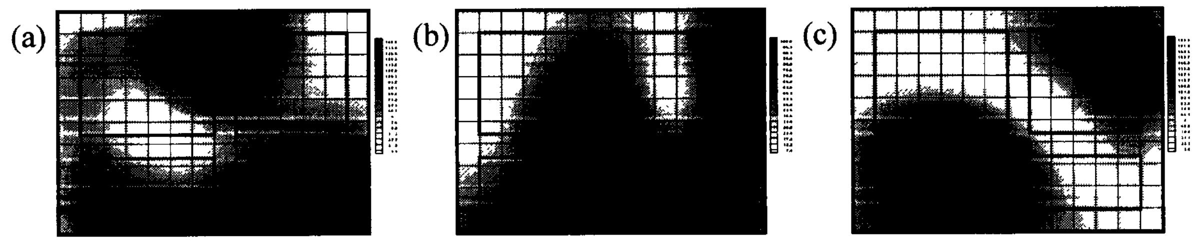

Fig.9. Distribution of calculated sound pressure level on the measurement field plane at 450 Hz. (a) set 4, (b) set 1, (c) set 5.

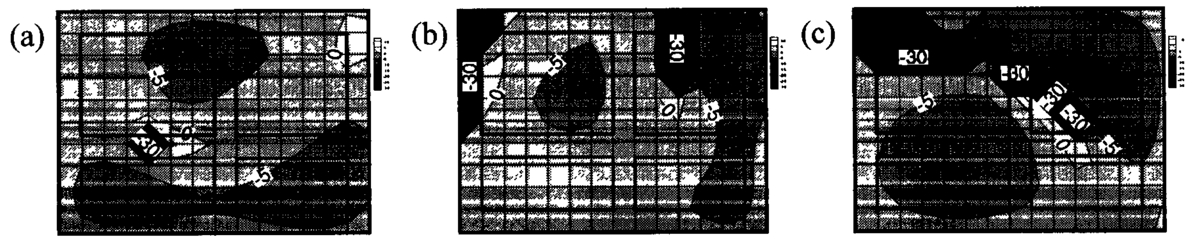

Fig.10. Reactivity index level on the measurement field plane at 450 Hz. (a) set 4, (b) set 1, (c) set 5.