Extraction of High Contributing Vibration Mode to Vehicle Interior Road Noise using Operational TPA and CAE Combination Analysis

Junji Yoshida[1], Ryo Majima[1], Daiki Hayashi[1], Junki Isemura[1]

[1] *Osaka Institute of Technology, 5-16-1, Omiya, Asahi-ku, Osaka, 535-8585, Japan, Email: junji.yoshida@oit.ac.jp*

Abstract

In this study, we developed a method which enables us to extract important CAE vibration modes from a lot of modes which gives large influence to vehicle interior road noise at the actual running condition. Firstly, we carried out operational test using a simple body panel vehicle model, and four exciters gave random input forces from under the four tires for imitating the vehicle running on a rough surface road. We measured vibration acceleration signals at multiple points of the body panel for carrying out operational TPA (OTPA). Subsequently, high contributing principal component (PC) mode of the target vehicle panel to the interior noise at the operational condition was analyzed by applying modified OTPA method which focuses the PC contribution. After then, high contributing and very important CAE vibration modes were extracted from a lot of simulated CAE vibration modes by evaluating the mode shape similarity between the high contributing PC mode and the CAE vibration mode. In addition, the interior noise level could be decreased very well by applying an intensive countermeasure to the high contributing vibration mode using CAE response analysis and the PC contribution analysis result.

Back ground & Purpose

For the effective countermeasure to vehicle interior noise, finding out high contribution part and applying intensive countermeasure to the part is essential. Operational TPA[1]-[3] is one of the methods to obtain contribution of each part (reference point) to the interior noisae such. However, if each reference point has strong correlation each other by a large vibration mode, specifying unique high contributing part becomes hard. On the other side, vibration mode of the target structure is very important information for considering the suitable countermeasure. We can obtain accurate vibration modes by simulation technique owing to the recent progress of CAE and increasing of computer power. However, all vibration modes of the target structure are not to be excited always in the actual operational condition depending on the actual input position and the frequency characteristic of the input force. In such a case, understanding which vibration modes are actually excited at the condition is important for the intensive countermeasure. Furthermore, if we can find out which actual excited vibration modes have significant influence on the vehicle interior noise as shown in Fig. 1, the extracted mode can be regarded as the most important mode and we can concentrate how to measure the mode by utilizing various CAE technique.

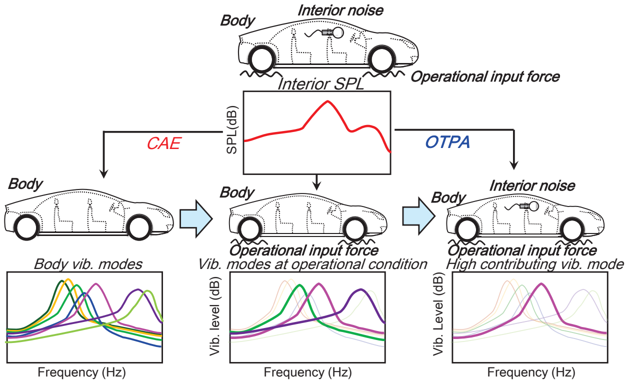


Figure 1: High contributing vibration mode in a lot of vibration modes of the target structure.

In this study, we propose a method to find out high contributing vibration modes utilizing modified OTPA method and several CAE techniques. In the method, we tried to extract which vibration mode had significant influence to the vehicle interior noise through the proposed combined analysis method using operational TPA and CAE technique.

Operational TPA PC model and high contributing PC mode

In this method, operational TPA is applied to the multiple vibration and sound pressure signals obtained simultaneously from the vehicle at the operational condition. In this test, small vehicle model was used and random input forces were given from under the four tires for imitating the vehicle running on a rough road as shown in Fig. 2.

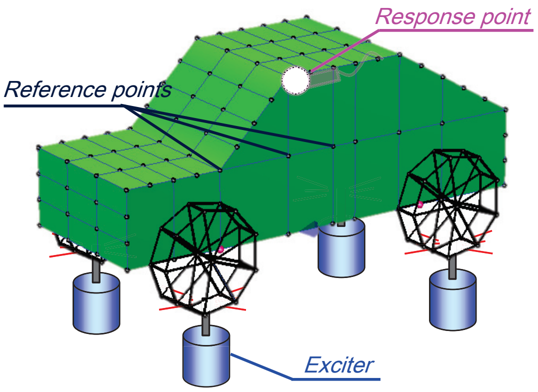


Figure 2: Operatinal test condition imitating a vehicle running on a rough surface road.

Figure 3 shows the averaged SPL in cabin. The SPL was observed to have large peak at 200 Hz. Hence, reduction of the SPL of this frequency band is necessary to decrease the overall SPL.

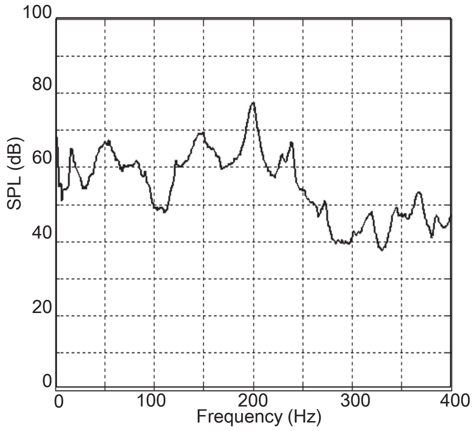
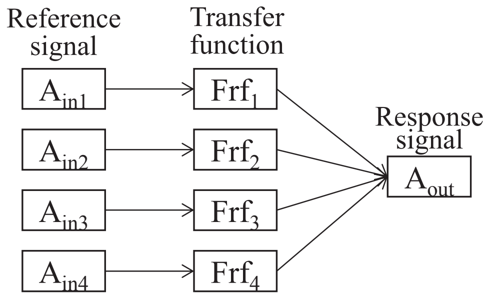
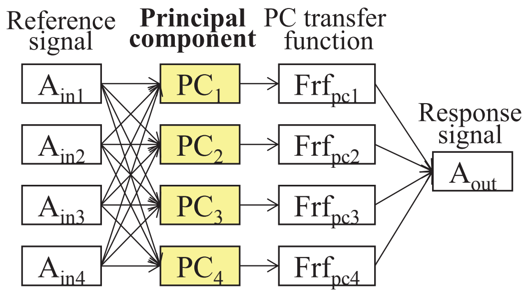


Figure 3: Averaged vehicle interior noise SPL at the operational test.

After then, principal component (PC) contribution was calculated by the modified OTPA model as shown in Fig. 4. In the original OTPA model, reference point contribution is calculated as shown in Fig. 4(a), but PC contribution is obtained in the modified model as shown in Fig. 4 (b). [4],[5]. The PC is calculated by singular value decomposition to the reference point matrix and does not have any correlation with the any other principal component.



(a) Original OTPA model.



(b) Modified OTPA model for PC contribution.

Figure 4: Operatinal TPA model. (a) is the original model for calculating reference signal contribution. (b) is the modified OTPA model for obtaing the PC contribution.

For applying this method, vehicle interior noise and a lot of vibration acceleration signals (over 100 points) were measured simultaneously. Figure 5 shows the PC contribution obtained by the modified OTPA. PC1 had dominant contribution to the interior noise at 200 Hz. This indicates reduction to the PC1 is effective way to the interior noise reduction at 200 Hz.

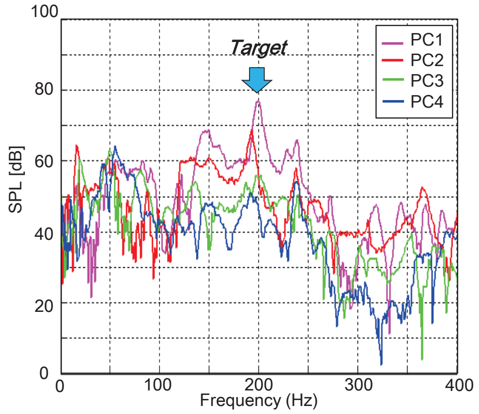


Figure 5: PC contribution obtained by applying the modified OTPA model to the simultaneously measured vibration acceleration signals and sound pressure signal in cabin.

In this method focusing PC contribution, each PC contribution is calculated by multiplying the PC level and PC transfer function as shown in Fig. 6.

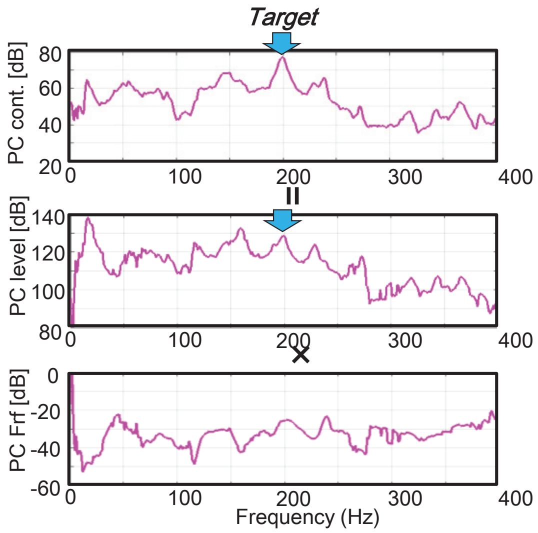


Figure 6: PC1 contribution, PC1 level and PC1 transfer function. The PC contribution is obtained by multiplying the PC level and PC transfer function.

From the result, the large PC1 contribution at 200 Hz was obserbed to be made by the PC level. Then, the vibration behavior of the PC1 (PC1 mode) at 200 Hz was obtained. Figure 7 shows the PC1 mode at 200 Hz.

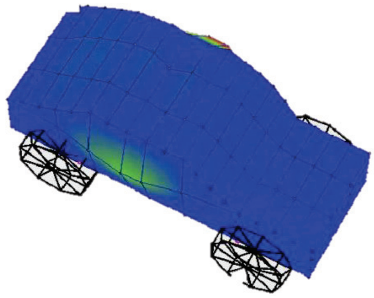
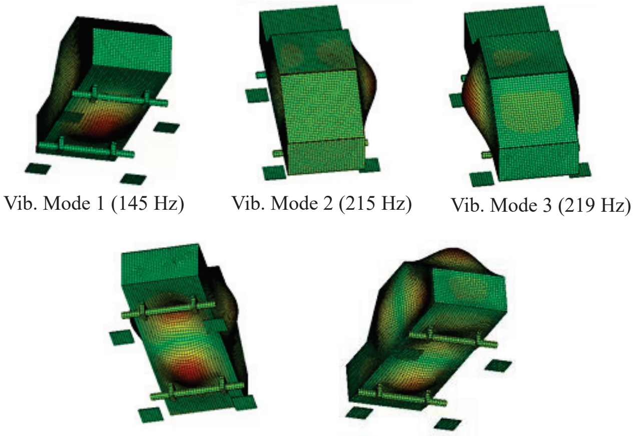


Figure 7: High contributing PC1 mode at 200 Hz.

This is the main contributing vibration behavior which increasing the interior noise at 200 Hz (high contributing PC mode). For the reduction of this interior noise, measuring this vibration behavior is better way.

High contributing CAE mode

Not only the vibration behavior (PC mode shape) of the target structure but also the physical characteristics of the mode becomes more useful information for applying suitable countermeasure to the high contributing PC mode in the structure modification. Then, CAE (eigen value analysis) was applied to obtain the vibration mode of the vehicle body panel. Figure 8 shows the obtained CAE vibration modes around 200 Hz.


Vib. Mode 1 (145 Hz) Vib. Mode 2 (215 Hz) Vib. Mode 3 (219 Hz)

Vib. Mode 4 (253 Hz) Vib. Mode 5 (285 Hz)

Figure 8: Simulated vibration modes around 200 Hz.

Here, not all vibration modes are not excited at the operational condition because of the frequency characteristic of the input force and the input points. Accordingly, high contributing CAE vibration mode were extracted among a lot of modes to carry out intensive counteremeasure to the structure as follows. To associate CAE mode with the high contributing PC mode, the mode shape correlation was calculated between the PC1 mode and several CAE vibration modes around 200 Hz as shown in Eq. 1.

$$\text{Mode shape correlation} = \left| \frac{\sum_{i=1}^{N} (P_i - \overline{P})(M_i - \overline{M})}{\sqrt{\sum_{i=1}^{N} (P_i - \overline{P})^2} \sqrt{\sum_{i=1}^{N} (M_i - \overline{M})^2}} \right| \quad (1)$$

i: Reference point number
N: Total number of reference point
P: Amplitude of PC mode
M: Amplitude of Vibration mode

Table 1 shows the mode shape correlation between the high contributing PC1 mode and the CAE vibration modes.

Table 1: Mode shape correlation between high contributing PC1 mode and the CAE vibration modes around 200 Hz.

Mode shape correlation		*Vibration mode*				
Frequency (Hz).		145	215	219	253	285
PC mode	200	0.20	0.14	**0.84**	0.24	0.37

As the result, a vibration mode at 219 Hz had very high correlation with the high contributing PC mode. This is the high excited and high contributing vibration mode to the vehicle interior noise at 200 Hz in this operational condition.

Countermeasure using CAE & OTPA PC model

By using the information of the high contributing vibration mode and CAE response analysis, the countermeasure for reduction of SPL peak at 200 Hz in cabin was considered. In this high contributing vibration mode, both side panels vibrated to the opposite direction, thus solid bar was inserted as the countermeasure instance as shown in Fig. 9.

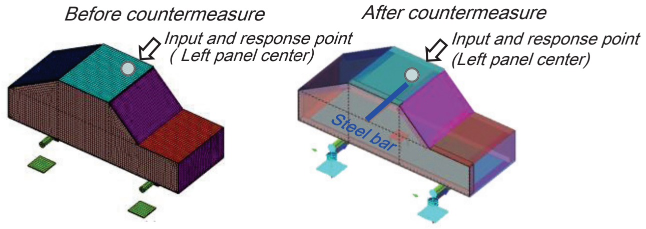


Figure 9: Countermeasure to the high contributing vibration mode at 200 Hz.

For evaluating the influence on the vibration at the center of the left side panel, point inertance was calculated by CAE response analysis. Figure 10 is the comparison of the point inertance before and after countermeasure.

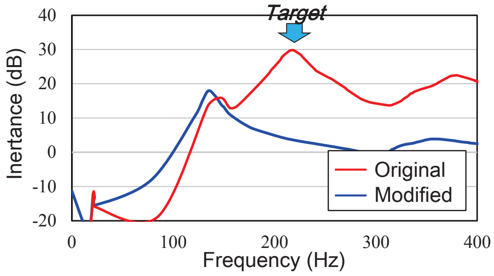


Figure 10: Point inertance comparison before and after countermeasure by CAE response analysis.

As the result, the point inertance was observed to decrease over 20 dB. As the final verification, the operational test was again performed and the vehicle interior noise was recorded before and after the countermeasure as shown in Fig. 11.

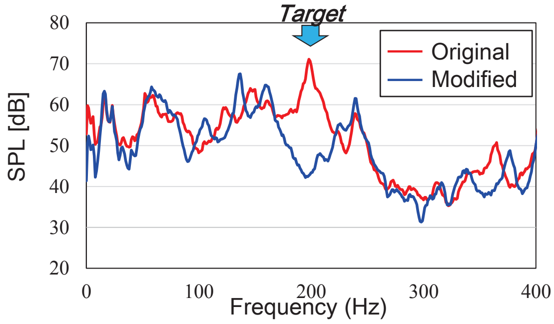


Figure 11: Vehicle interior noise comparison before and after the contermeasure obtained by the experiment.

The result showed the interior noise was reduced over 20 dB only at the 200 Hz band. This indicates the vibration mode was actually had high contribution at 200 Hz in the operational condition.

Summary

In this method, we considered how to find out most important vibration mode among a lot of modes by using modified operational TPA method and CAE technique. PC mode obtained by the modified OTPA method was utilized to realize it. By associating the high contributing PC mode obtained by the experimental OTPA method and CAE mode, high contributing (most important target) vibration mode was extracted. The accuracy was also verified through the countermeasure test. In addition, this has a possibility to help us to estimate appropriate physical property to reach the target interior noise level by using the combined experimental OTPA and CAE methods.

Acknowledgments

The authors thank Mueller-BBM in Germany and TOYO cooperation in Japan for supporting this work.

References

[1] Noumura K, Yoshida J. Method of Transfer Path Analysis for Vehicle Interior Sound with No Excitation Experiment. Proc FISITA 2006 World Automotive Congress; 22-27 October 2006; Yokohama, Japan 2006. p. 1-10.

[2] Lohrmann M. Operational Transfer Path Analysis: Comparison with Conventional Methods. Proc 15th ICSV; 6-10 July 2008; Daejeon, Korea 2008. p. 2671-2676.

[3] Klerk D, Ossipov A. Operational Transfer Path Analysis: Theory, Guidelines and Tire Noise Application. Journal of Mechanical Systems and Signal Processing. 2010; 24 (7):p.1950-1962.

[4] Yoshida J, Tanaka K. Contribution Analysis of Vibration Mode Utilizing Operational TPA. Mechanical Engineering Journal. 2016; 3 (1):p.1-15.

[5] Yoshida J, Tanaka K, Nakamoto R, Fukasawa K. Combination Analysis of Operational TPA and CAE Technique for Obtaining High Contributing Vibration Mode.