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A design technique for reducing the intake noise of a vehicle

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ABSTRACT : The intake noise of a vehicle is analyzed and reduced by using the transfer matrix method as well as the FE analysis code, NIT/SYSNOISE. A speaker excitation system is also proposed, which can analyze the acoustic characteristics of the intake system. It is easy to analyze the intake noise in the laboratory environment, and can be used at an early design stage of the intake system development. And this study proposes the improvement to reduce the level of the intake noise. It is to select the optimum position of a resonator and verified by NIT/SYSNOISE, FE analysis commercial software and testing the prototype and a proposed speaker excitation system.

1. Introduction

The intake noise, a major source of the vehicle noise, was studied to reduce the level of the noise for many years, since the quiet passenger compartment was notified as an important quality for a vehicle. The intake noise is a low frequency noise up to about 600 Hz and a factor not only affecting the exterior but also causing a booming noise in the interior. Traditionally, the intake noise has been analyzed and improved by the road test or the experiment using the engine dynamo in a laboratory, namely, the trial and error approach. These approaches require very high cost, long time consuming and the large size laboratory environment and equipment.

Recently, the various software tools and the analysis technique have been proposed to analyze and improve the intake noise. Specially, the transfer matrix method and the acoustic finite element analysis have been considered as useful things at the early stage of development of intake systems. The finite element analysis is more useful at the concept stage of the development of the intake system. But once presented with a detail design problem, FE analysis is not a practical tool anymore. This is because the relative high cost and analysis time are required in re-modeling and gaining sufficient accuracy, while the transfer matrix method is easy to analyze the intake system but this method is applicable for the only simplified model. So the technique is useful at concept design stage of a intake system.

And the simulator must be used to verify the acoustic characteristic of the proposed model by various analysis techniques. In general, the intake noise has been analyzed by the real road test or the experiment using the engine dynamo. Another method is rotating the crankshaft with an electric motor, but it has some disadvantage that the analysis requires the large power motor and generates additional motor noise contaminating the objective one for a intake system. And the other one that put a speaker in each cylinder instead a piston and excites the air intake system with same phase difference as the firing of a real, was proposed. In a real rotating engine, when a cylinder valve is opened, rest valve are closed, therefore the manifolds of closed valve is operated as the quarter wave resonator. So this method is not expected the exact analysis.

In this study, the testing apparatus of the intake system which can use in a laboratory environment without additional noise and the exhaust gas, is proposed. That has a speaker in only one cylinder of opened valve instead a piston and rest valves are actually closed by the tuned camshaft angle. The characteristic of the intake noise is like as a real. This study analyzed the real intake system using the transfer matrix method and FE analysis, NIT/SYSNOISE and the proposed model to select the position of a resonator. And these are verified by the speaker excitation system.

2. Speaker excitation system for the analysis of the intake noise

The speaker exciting system is proposed using a current four-cylinder 1.8 liters engine. The crank shaft, connecting rods and pistons are removed from the engine and then a speaker is set into the lower dead center of a cylinder. The cylinder with a speaker is selected by the estimating of affect, this study select the cylinder most far from inlet hose.

The camshaft has four cams in this case. Cams are fixed on the shaft with tuned angles. The intake valves are driven by the cams on the shaft. While a intake valve is opened, rest valves are closed. The closed manifolds of intake system operate as the quarter wave resonator (about 170Hz and 180 Hz in this case). Analysis frequency range are 1000 rpm~5000 rpm (about 35 Hz ~ 165 Hz) and the exciting frequency increment is 150 rpm (5 Hz). The order tracking of the frequency response and the overall level are measured by the sound level meter at each condition. The excitation is derived by the signal generator and the amplifier, and the excitation frequency is controlled by Eq. (1)

$$freq.(Hz) = n \times rpm \times cyc \times \frac{1}{60} \quad (1)$$

where, *freq.* is the exciting frequency, *n* is the harmonic order, *rpm* is the revolution of the engine and *cyc* is the number of cylinders.

Fig. 1 shows the experimental configuration of the intake system for the vehicle using a speaker exciting system. The speaker has 3inches diameters and 3 watts power, which is excited by a signal generator and an amplifier. The sound level meter is used to measure A-weighting noise signals. The signals are analyzed by a spectrum analyzer and a computer. The measuring point of the intake noise is located 45 degree and 0.1 m vertically from the intake entrance.

In Fig.2, the normalized sound pressure level obtained from the real engine is compared with that from the speaker excitation system for the verification. Two sets of the data are relatively in good accord.

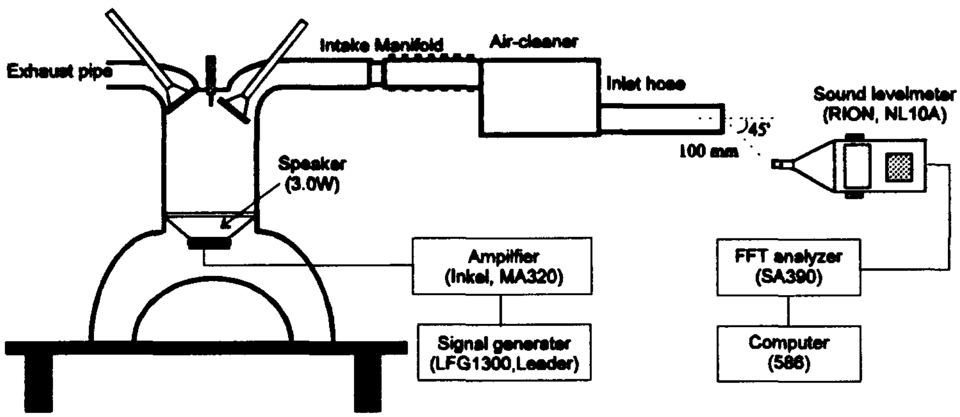


Fig. 1 Experimental configuration using acoustic excitation system with speaker

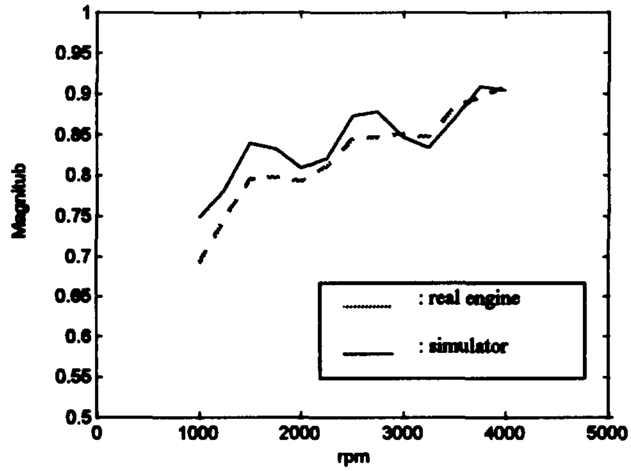


Fig.2 Normalized SPL of the simulator and the real engine at each excitation rpm

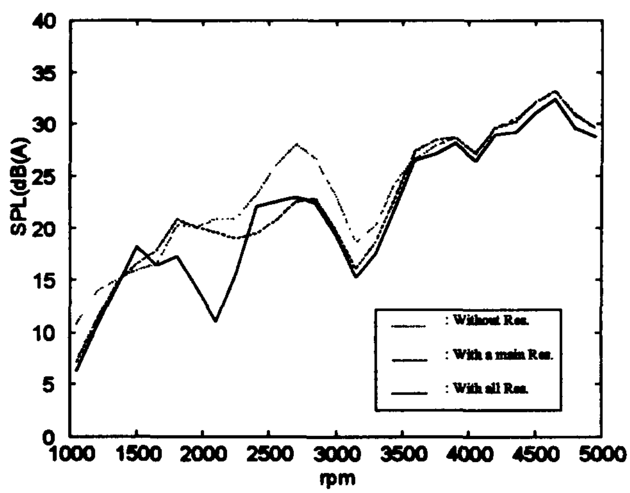


Fig. 3 Sound pressure overall levels of a simulator at each rpm

The test intake system has two resonators: the tuning frequency of main resonator is 87Hz and the frequency of the auxiliary one is 75 Hz. Fig.3 shows the acoustic characteristics of the three cases: 1) the case without resonator, 2) the case with a main resonator and 3) the case with both resonators. It is shown that in the case without resonator the sound pressure level is relatively dominant at about 2700 rpm (87 Hz). This means that the resonance is caused by the excited air column in intake system at 87Hz. The main resonator is installed to reduce the noise of that, but the installation of the main resonator cause the resonance at 2000 rpm~2500rpm. And the auxiliary resonator is installed to improve the resonance of 75 Hz, but cause the resonance at 1700 rpm~2100rpm. Fig. 4 shows the order tracking of the intake noise using the speaker excitation system and the resonance of 70 Hz uncorrelated with the excitation frequency. Since this resonance is in the general usage revolution of the engine, the improvement must be needed.

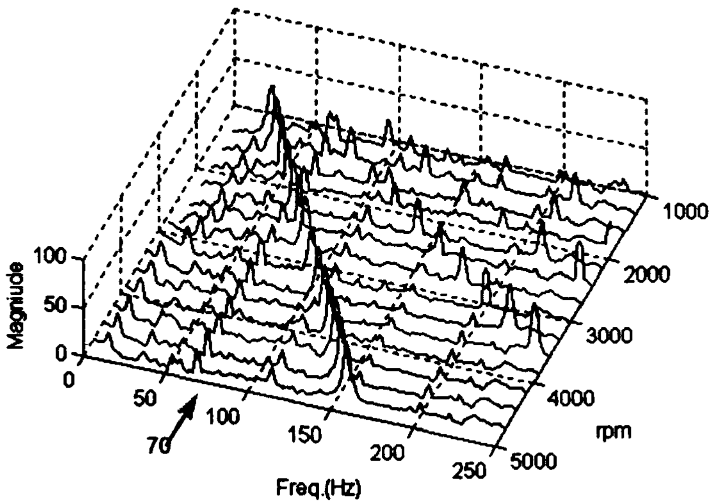


Fig. 4 The order tracking of intake noises at each excitation rpm

3. Analysis of intake noise using the conventional method

The transfer matrix method and the finite element analysis using NIT/SYSNOISE are used to verify theoretically the previous analysis result and to propose improvement for selecting the optimum position of the main resonator. Fig. 5 shows that the transmission losses are obtained by the transfer matrix method and the experiment using the two microphones method. It is shown that the prediction using transfer matrix method is well agree with the measurements; therefore the transfer matrix method can be used in the analysis, the design and the improvement for the intake system.

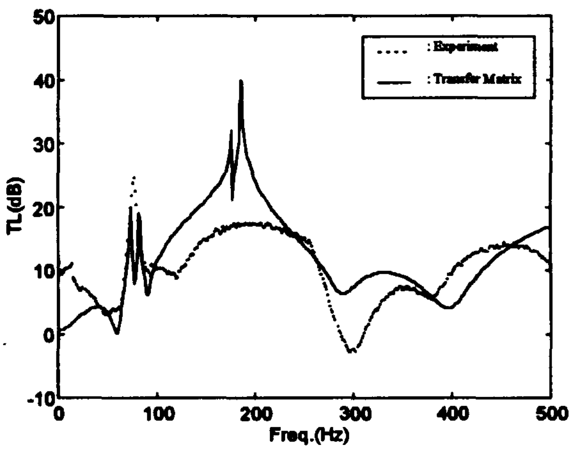


Fig. 5 Transmission losses of the intake system

The FE model and the analysis results of the intake system is shown in Fig. 6, where the transmission losses by NIT/SYSNOISE are nearly the same as those of the transfer matrix method. In this study, as the main resonator is moved from the intake entrance to the air cleaner with 5 cm increment and the transmission losses are compared at each positions using the transfer matrix method. Fig. 7 shows the analysis results. It is shown that the more close the resonator move to the air cleaner, the less the resonance of 75Hz is, but that make the resonance at 110Hz. Since the noise of 110Hz(3300 rpm) is generally in high speed range, the noise is heard relatively smaller than low frequency noise, and also the booming noise is not caused.

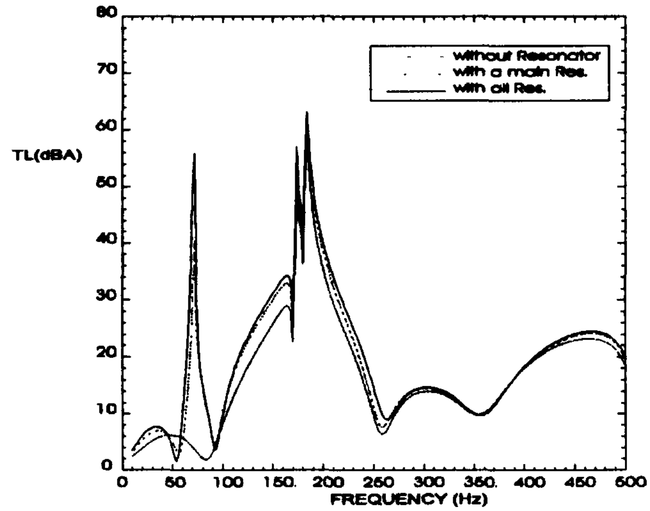
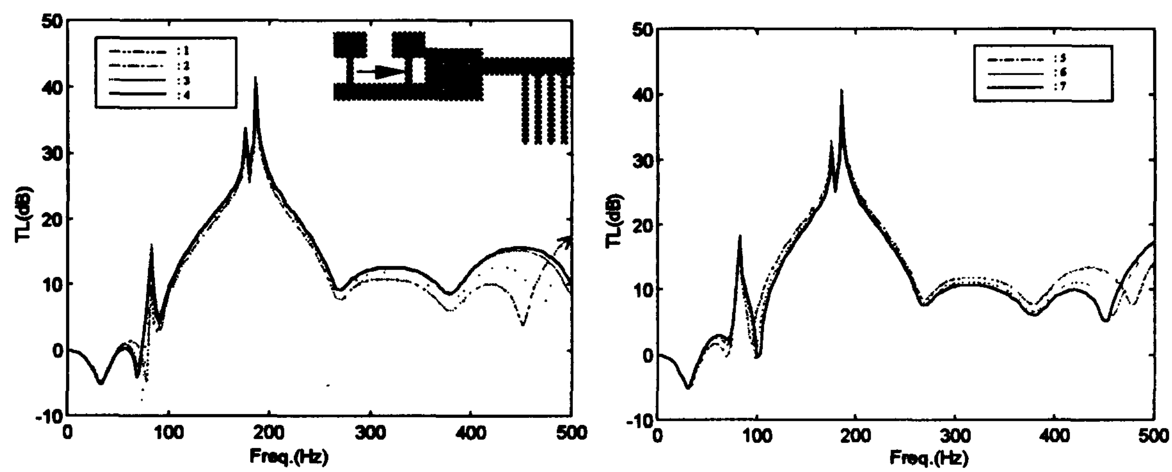


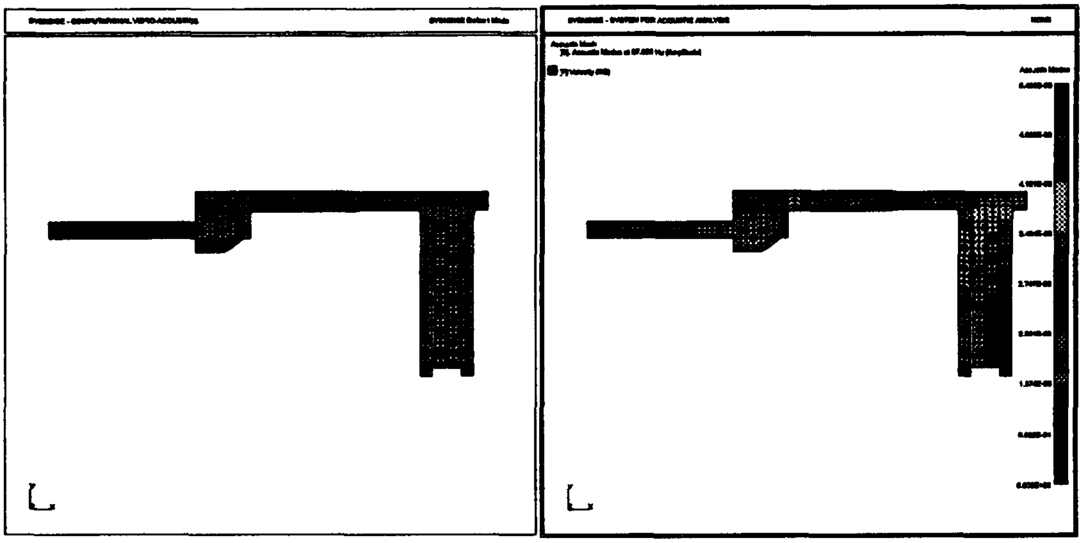
Fig. 6 Estimated TLs of the intake system using NIT/SYSNOISE

The location of a resonator is generally determined on the basis of the pressure anti-modal points of the mode shapes. Maximum attenuation is achieved at or near the anti-modal points. The acoustic mode shape analysis using NIT/SYSNOISE is performed to find anti-modal points of 87 Hz. Fig. 8 shows the FE model and the acoustic mode shape of 87 Hz. It is shown that the anti-modal point is at the air cleaner and this analysis result is the same as that of the transfer matrix method. Based on these analysis results, this study proposes the modified intake system with a new location of the main resonator on the air cleaner.



(a) #1 ~ #4 (b) #5 ~ # 7

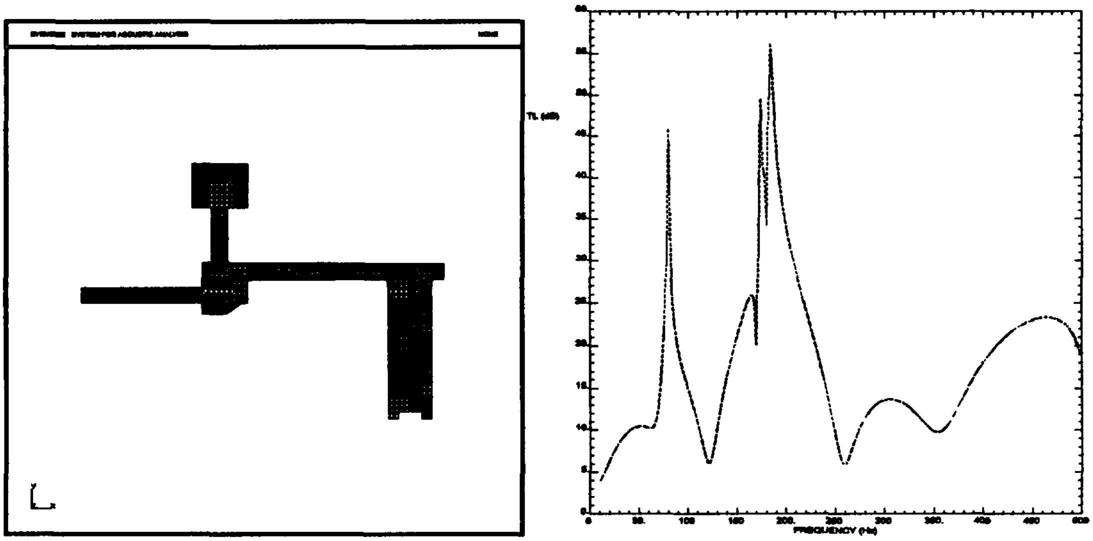
Fig. 7 Estimated TLs at each position of a main resonator using the transfer matrix method



(a) FE model (b) acoustic mode shape (87Hz)

Fig. 8 FE analysis using NIT/SYSNOISE

Fig. 9 shows the FE model and the transmission loss obtained by NIT/SYSNOISE. Fig. 10 shows the overview of the prototype of the proposed intake system. Fig. 11 shows comparison of the transmission losses obtained by the transfer matrix method and the measurement using the prototype. Similarly with the previous prediction, the resonance of 75Hz is improved considerably, and resonance of 110 Hz is caused.



(a) FE model (b) transmission loss

Fig.9 FE analysis of the modified intake system using NIT/SYSNOISE

The sound pressure levels are measured to verify the acoustic characteristic of the proposed prototype using the speaker excitation system. Fig. 12 shows that the intake noise characteristic of the modified system with the new location of a resonator are compared with those of the original system with a main resonator as well as the original system with all resonators. The order tracking of the modified intake system is shown in Fig. 13.

Fig. 10 Overview of a prototype of an intake system

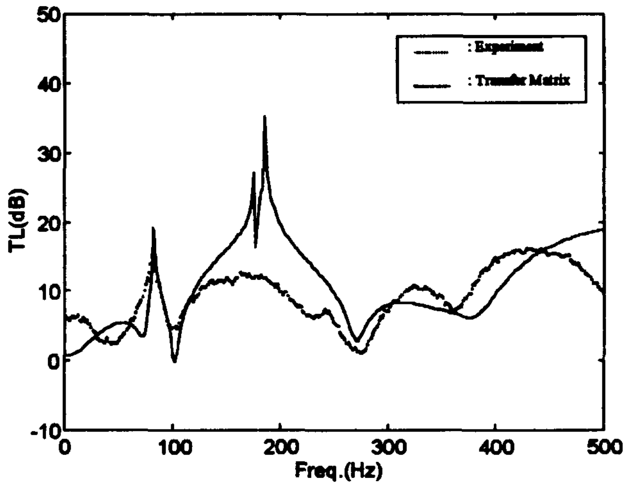


Fig. 11 Transmission loss of an intake system with modified position of a resonator

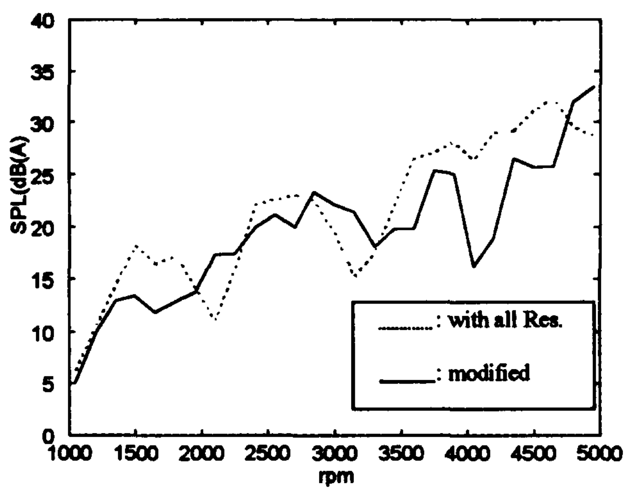


Fig.12 Sound pressure overall level at each excitation rpm

The intake noise of the modified system with only one resonator is lower than that of the original with two resonators on the whole range except at 3300 rpm (110Hz).

And it is known that the more the revolution speed of the engine increase, the louder the intake noise is heard. If this tendency is considered, the intake noise of the modified system is superior to that of the original in the side of the sound quality.

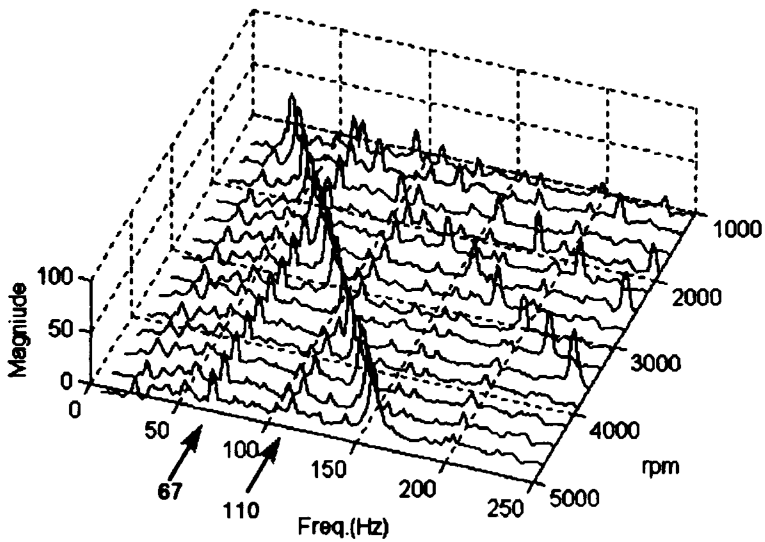


Fig. 12 The order tracking of the modified intake system

4. Conclusions

The speaker excitation system is proposed, which can analyze the acoustic characteristics of the intake system and be used at the early design stage of the development.

The intake noise of a current intake system is analyzed by the transfer matrix method, the experiment using the two microphones method and the finite element analysis using NIT/SYSNOISE. Improvement to select the optimum location of a resonator is also proposed to reduce the intake noise efficiently by the computer simulation. The improvement is verified by the prototype and the speaker excitation system.

Referances

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