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INTERIOR NOISE REDUCTION IN A VEHICLE BY SENSITIVITY ANALYSIS OF ENGINE EXCITATION FORCES

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1. INTRODUCTION

In order to identify complicated vibratory transmission mechanisms it is required to make an adequate model of vibratory input and transmission mechanisms.[1][2]

In this paper, a multi-input/multi-output system is modeled between engine vibration and interior noise of a vehicle. To understand how much and what component of engine excitation forces has an effect on interior noise, the concept of effectiveness was introduced. To find out the effective input magnitude and phase change for reduction of interior noise the sensitivity analysis of each input component to interior noise was performed.

A simulation of input components change was carried out and the trend of vector change for synthesized output was visualized in the vector synthesis diagram. Subsequently, quantity of input change from current design conditions for reduction of interior noise was suggested.

2. ANALYSIS MODEL FOR INTERIOR NOISE OF A VEHICLE

Sound pressure at a point in a vehicle can be expressed as follows :

$$P_r = \sum_{ni} H_{nir} F_{ni} + P_e H_{er} \quad (1)$$

where, P_r : sound pressure vector at point r in the vehicle compartment

P_e : sound pressure vector at a point in the engine compartment

H_{er} : acoustic frequency response function between the engine compartment and point r.

H_{nir} : frequency response function between force acting direction i, mount point n and sound pressure at point r.

F_{ni} : force acting direction i at point n

i : direction at rectangular component axis
n : number of mounting point

All the variables of equation (1) have their magnitudes and phases respectively, and each phase has a time delay in respect to the reference signal. Since structure-borne sound has more effect on the interior booming noise than air-borne sound, the equation can be approximated as follows :

$$P_r = \sum_{ni} H_{nir} F_{ni} \tag{2}$$

3. SENSITIVITY ANALYSIS

Sensitivities of output to variation of each input component were calculated. If $|P_r|$ is differentiated with respect to magnitude and phase of each input component vector, sensitivities can be obtained through the following equations :

$$\frac{\partial |P_r|}{\partial |F_i|} = \frac{|H_{ir}|}{|P_r|} \sum_{j=1}^{n} |H_{jr}| |F_j| \cos[\ (\phi_i + \phi_i) - (\phi_j + \phi_j)] \tag{3}$$

$$\frac{\partial |P_r|}{\partial |\phi_i|} = \frac{|H_{ir}| |F_i|}{|P_r|} \sum_{j=1}^{n} |H_{jr}| |F_j| \cos[\ (\phi_j + \phi_j) - (\phi_i + \phi_i)] \tag{4}$$

where,

ϕ_i : phase angle of H_{ir}
ϕ_i : phase angle of F_i

4. EXPERIMENT

An experiment was performed with a passenger car whose engine is supported by the chassis at 3 points and whose exhaust capacity is 2,000cc. To investigate the characteristics of transmission paths, the vibration and noise systems were modeled as 9 input components and 2 outputs. Input components were signals of exciting forces applied in 3-axis directions respectively at 3 body points. These are known as primary transmission paths of engine vibration. Outputs were signals of sound pressure measured at the front & rear seats. To obtain exciting forces, engine vibration was initially measured as 3-axis directional accelerations at the engine side point of each mount and body vibration. To obtain body vibration force-acoustic transfer functions were measured without the attachment of the engine and transmission. Fig. 1 represents experimental instrument's setup for vibratory displacement measurement. Simultaneous data acquisition of accelerations at each point of input and output was performed the idle state and 2,025 engine rpm state respectively. Input and output signals were amplified by amplifier(2635, B&K) and were recorded on signal recorder(XR-7000, TEAC). All the sound pressure signals are A-weighted. Digital data obtained from FFT analyzer(SA-390) was delivered to a personal computer. A database for application of vector synthesis analysis was set up with this data.

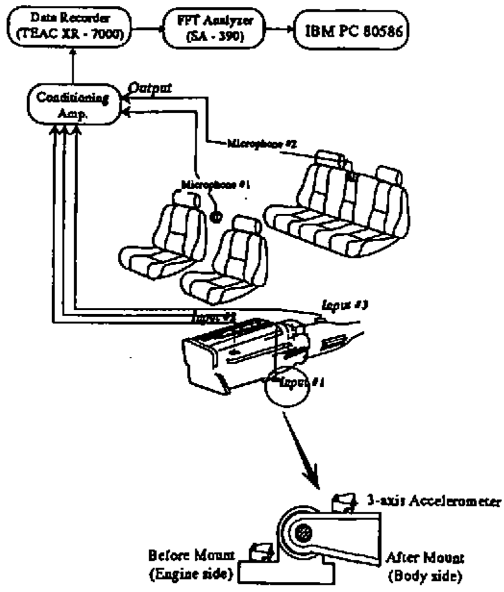


Fig. 1 Experimental setup for measurement of vibrational displacement

5. RESULTS AND DISCUSSIONS

Sensitivity Analysis Of Input For Interior Noise In A Vehicle

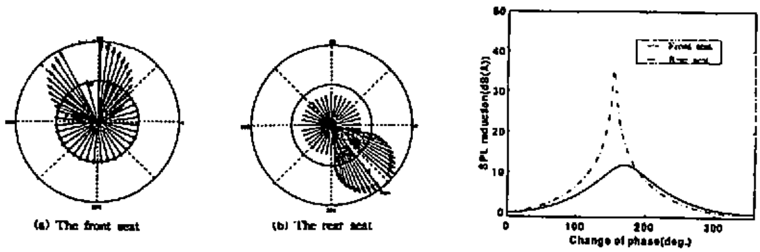
The sensitivities of magnitude and phase variations of each force transmitted from each mount to synthesized sound pressure vectors are represented in Table 1. If magnitude of force transmitted in vertical direction through the power train mount is reduced, interior sound pressure for 67.5 Hz will be reduced effectively in the front seat. If phase of force transmitted in vertical direction through the left engine mount is changed properly, interior sound pressure for 67.5 Hz will be reduced effectively in the front seat.

Prediction Of Interior Sound Pressure

The vector loci of each component sound pressure and synthesized sound pressure were investigated with respect to changing phase of each input excitation force. Typical vector loci of synthesized pressure of input excitation forces was represented in Fig. 2. The phase variation range of each input excitation force for reduced interior sound pressure can be calculated.

Table 1. Sensitivity of each input for front seat & rear seat SPL

Input Position		Sensitivity of Mag. (Pas/N)	Sensityvity of Phase (Pas/rad)	Sensitivity of Mag. (Pas/N)	Sensityvity of Phase (Pas/rad)
		Front seat		Rear seat	
LH E/G MTG.	X(#1)	-1.340e-3	-2.993e-5	-3.006e-3	-3.174e-4
	Y(#2)	-2.237e-4	-5.430e-6	-9.562e-4	2.538e-4
	Z(#3)	1.319e-3	2.568e-4	6.523e-3	6.391e-4
RH E/G MTG.	X(#4)	1.774e-3	4.326e-5	-2.088e-3	-1.117e-4
	Y(#5)	-2.412e-4	-3.049e-5	-1.568e-3	7.743e-5
	Z(#6)	1.023e-3	-3.477e-4	7.890e-3	-1.403e-4
T/M MTG.	X(#7)	-2.472e-3	-1.290e-4	-3.161e-3	3.227e-5
	Y(#8)	1.576e-4	1.525e-4	7.377e-4	-2.285e-4
	Z(#9)	4.819e-3	9.001e-5	7.353e-3	-1.045e-4



(a) The front seat (b) The rear seat (c) SPL reduction of the front and rear seat

Fig. 2 Synthesized vector loci of front & rear seat corresponding to change of phase of LH E/G MTG. (z) #3

6. CONCLUSIONS

In this study, the sensitivity analysis of exciting input forces also gives useful information for interior noise reduction together with effectiveness. When changes in magnitudes and phases of input forces transmitted from the engine mount system are assumed, the changes in sound pressure at the front and the rear seats were predicted. The reduction of forces transmitted in vertical direction through the left and right engine mounts is suggested as an effective way of reducing interior noise.

REFERENCES

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[2] J-E Oh, J. H. Cho, J. D. Kim, KSME, 19, 1, pp. 14-21(1995)