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Vibro-Acoustic Prediction by Mechanical Impedance Method

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Summary

Satellite equipment experience severe high random acoustic loads during launch phase. [1] Accurate prediction of this random vibration is demanded to prevent equipmtnt from trouble. In this paper, a new approach for vibro-acoustic coupling analysis is proposed to obtain more accurate prediction. The proposed method applies Mechanical Impedance Method to vibro-acoustic coupling analysis with FEM model of structure and SEA model of sound system.
The analysis of simple model is conducted to study the proposed method. The result from the comparison shows this method provides more accurate prediction with structure impedance calculated from area-excitation analysis than from point-excitation analysis.

Introduction

Satellite equipment experience severe high random acoustic loads like jets boom during launch phase of a spacecraft. The random vibration of satellite equipment panels which is excited by the former acoustic loads is a critical design consideration in satellite development. The prediction of this random vibration is required in the early stage of satellite design in order to specify the random vibration environments of satellite equipment.

At present, the prediction of satellite equipment panels vibration that is coupled with acoustic system use FEM in low frequency and SEA[2] in middle and high frequency. Only the mean energy vibration level can be obtained in SEA. Therefore some of equipment components may be practically expose to higher vibration level than SEA result. It is demanded to predict each equipment components behavior.

The Proposed Method

Mechanical Impedance Method predicts the vibration response of two point-connected structures at connected point. Assume that a structure L is connected to a structure S at point i as shown in Figure 1. When the exciting force F is applied at point d of S, the vibration response v_i at i can be descraibed by

$$v_i = \frac{1}{1+Z_{ii}^L/Z_{ii}^S} v_{i0}, \tag{1}$$

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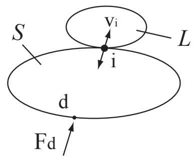

Figure 1: Connected structure

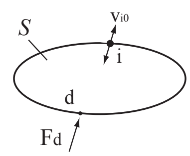

Figure 2: Unconnected structure S

where v_{i0} is the vibration response at i of unconnected S as shown in Figure 2, each of Z_{ii}^L and Z_{ii}^S is the driving impedance at i of each structure.

We propose to predict vibration response of structure coupled with acoustic system using Mechanical Impedance Method. This method predicts the vibration responce of the structure coupled with acoustic system as the following equation.

$$v_{with\,air} = \frac{1}{1+Z_a/Z_s} v_{w/o\,air} \tag{2}$$

Analysis of the Simple Model

Analysis of the simple model which consists of a plate with backcavity as shown in Figure 3 is conducted to study the proposed method. Specification of the model is shown in Table 1

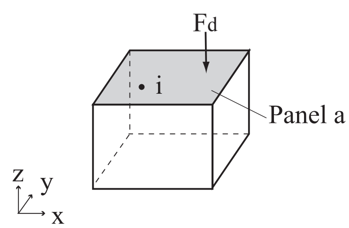

Figure 3: Simple model for analysis

Table 1: Specification

Panel		Cavity	
Density $[kg/m^3]$	2.70×10^3	Density $[kg/m^3]$	1.21×10^3
Young's modulus $[Pa]$	7.00×10^{10}	Acoustic velocity $[m/s]$	50
Thickness $[mm]$	1.50	Dimensions $[m^3]$	$0.6\times0.4\times0.7$
The location of i	(0.17 0.12 0.70)		
The location of d	(0.396 0.23 0.70)		

We use the following theoretical coupling equations[3] to calculate the exact responce.

$$\ddot{p}_n + 2\zeta_n\omega_n\dot{p}_n + \omega_n^2 p_n = -\frac{\rho_0 c_0^2 A}{M_n}\sum_r C_{nr}\ddot{q}_r, \tag{3}$$

$$\ddot{q}_r + 2\zeta_r\omega_r\dot{q}_r + \omega_r^2 q_r = \frac{A}{M_r}\sum_n p_n C_{nr} - \frac{1}{M_r}\theta_r F_d, \tag{4}$$

where C_{nr} is demnsionless modal coupling coefficients integral over the coupling area A.

In the proposed method, mechanical impedance for the cavity and for the plate must be defined. With assumption that sound wave is plane wave, the impedance for cavity is described as

$$Z_a = \frac{pA}{v} = \rho_0 c_0 A. \tag{5}$$

Two types of the structural impedance for cavity is compared in this paper. One is the driving impedance defined as

$$Z_{s1} = \frac{F_i}{v_i} \tag{6}$$

where v_i is calculated from analysis of point-excited plate as shown in Figure 4. The other is the are-excited impedance defined as

$$Z_{s2} = \frac{pA}{v_i} \tag{7}$$

where v_i is calculated from analysis of area-excited plate as shown in Figure 5.

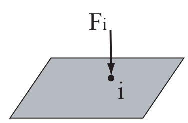

Figure 4: Impedance for point-excitation

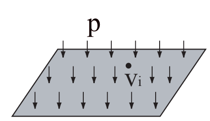

Figure 5: Impedance for area-excitation

Result

Figure 6 shows the analytical prediction by the proposed method and the exact responce. The proposed method using z_{s1} overestimate the responce in high frequency. The proposed method using z_{s2} can derive more accurate prediction.

The result in this comparison means Mechanical Impedance Method for vibro-acoustic analysis must consider not only the driving point impedance at the measurement point, but also the impedance at the measurement point when the exciting force is applied on other place.

References

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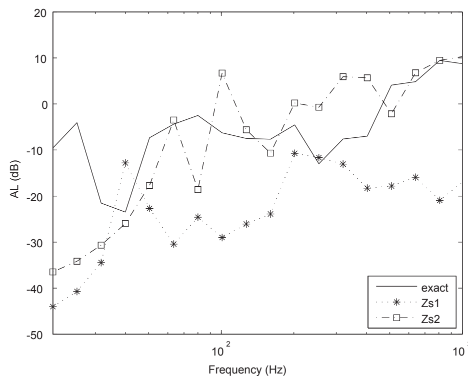

Figure 6: Acceleration level of panel

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