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EXPERIMENTAL ANALYSIS ON STRUCTURE-BORNE NOISE IN AN ENCLOSURE

[1]N. FATHIAH WAZIRALILAH, [2]AMINUDIN ABU, [3]NOR'AZIZI BIN OTHMAN,[4]SANDA PYAE SONE,[5]U.ALYAA HASHIM, [6]D. SHAKIRAH SHUKOR, [7]VIKNESHVARAN

[1, 2,4,5,6,7]Intelligent Dynamics System Laboratory, Department of Mechanical Precision Engineering, Malaysia-Japan Institute of Technology, UniversitiTeknologi Malaysia
[3]Memo-Bio Laboratory, Department of Mechanical Precision Engineering, Malaysia-Japan Institute of Technology, UniversitiTeknologi Malaysia
Email: [1]tiah14@gmail.com, [2]aminudin.kl@utm.my, [3]norazizio.kl@utm.my,
[4]philip.sanda@gmail.com,[5]realualy@gmail.com,[6]shakirahshukor@gmail.com,[7]viknesh_94@yahoo.com

Abstract - This paper present the experimental analysis conducted on a structure-borne noise in a rectangular enclosure prototype made by joining of sheet aluminum metal and plywood. The study is significant as the structural noise could cause annoyance and dizziness thus by deepening the comprehension on the structure-borne noise, the noise problem could be overcome. In this study, modal analysis is carried out to seek the structure's behavior in order to identify the characteristics of enclosure in frequency domain ranging from 1 Hz to 100 Hz. Here, numbers of modes are identified and the characteristic of mode shape is categorized. Modal experiment is used to diagnose the structural behavior while microphone is used to diagnose the sound. Spectral testing is performed on the enclosure and it is acoustically excited using shaker and as it vibrates, the vibrational and noise responses sensed by tri-axis accelerometer and microphone sensors are recorded respectively. The modal modes extracted from the experiment are validated by simulation performed using MSC NASTRAN/PATRAN software. From developed prototype, the structural behavior can be diagnosed and the mode shape can be determined. In the end of the study, the relation and major contribution of the structural and sound in the enclosure can be identified from the observation of both spectrums.

Keywords - Enclosure, Modal Analysis, Sound Analysis, Structure-Borne Noise.

I. INTRODUCTION

In our daily life, vibration and noise are the element that is constantly present in our high-tech society. Many discomfort occurs both at home and in the workplace are commonly caused by intrusion of noise thus obligation of reducing noise is a matter currently concentrated on by authorities in many countries [1]. Noise can be differentiated into two which are structure-borne noise and air-borne noise. Air-borne noise is transmitted by air and atmosphere while structure-borne noise is transmitted via solid structures. Structure-borne noise can be defined as the noise which is spreads in solid bodies and it is the sound that reaches a point in a building over at least part of its path that propagates by solid-borne transmission [2].

In our life, we are surrounded by many structure, the noise generated by vibration in the structure could cause annoyance and give us distraction. Therefore, a deep study and analysis on structure-borne is essential. For a high quality of life, performing well in a task is one of the key. Hence, a conducive which is a quieter environment is needed and an evidence shows that students in classrooms with soft surface flooring that can absorb unwanted noise well have higher levels of academic achievement, behavior, attention and concentration than those in classrooms without carpet [3]. It is crystal clear that noise can affect one's life productivity.

As year passed by, the search for constructible space has impel the building developer to implement their project much nearer to transportation corridors than previous project and this means the structure-borne noise has become the biggest contributor to the noise from transportation systems transmitted into buildings [4]. In addition ,as many machineries in a building such as fans, compressors, hydraulic equipment, electrical motors and air conditioning system can produce a substantial amount of vibration, the structure-borne noise is a never-ending demanding problem in engineering [5]. Therefore, inclusive knowledge of structure-borne noise analysis is important for all kind of vibration analysis.
K.W Ngai and C.F Ng presented an analysis on structure-borne noise by experimenting a simple concrete box and made validation using finite element method (FEM) [6] while Satish KonderaoDesmukh and Onkar Sunil Madhekar analyzed structure-borne noise in an acoustic enclosure of compressor using MSCPatran. Transfer Path Analysis (TPA) is proposed so that the dominated part of the structure can be shown by path and panel contribution [7]. Domadiya and ParthkumarGandalal presented an analysis of noise transmission in a lightweight two panel structure consisting of two plates with internal ribs performed using finite element model structured in the commercial FEM package ABAQUS [8].
However, the analysis on the structure borne-noise in different materials is fewly reported. Plus, there is little information available on the relation of the

structure mode and noise mode as most of previous work is only focusing on the modal analysis of the structure-borne noise. Modal analysis is a process whereby structure is described in term of its dynamic properties or also known as modal parameters which are the natural frequency, damping factors and mode [9]. In this paper, the analysis of structure-borne noise in an enclosure made of two different materials which are plywood and aluminum sheet metal is presented. The modal and sound analysis is carried out experimentally and then with the aid of simulation, the result is validated.

II. THEORY

The structure borne-noise process can be subdivided into four main stages as shown in Figure 1. The first stage is generation which comprises the origin of an oscillation. The second stage covers the transfer of oscillatory energy from the mechanism of generation to a structure. The third stage is propagation whereby the energy is distributed throughout structural system and fourth, any structure vibrating in an air environment will impart power to that air [10].

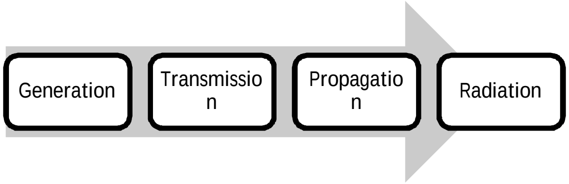

Figure 1. Four main stages in structure-borne process

In this study, the focus is set to the first stage. Here, the shaker is installed on the surface of sheet metal and this source is causing unwanted sound and vibrations at remote from the source location. For the case of the interaction between the flexible structure and the acoustic sound waves, the cavity walls react to the pressure within the cavity and in this case, the structural displacement couples with the acoustic pressure field. This calls for a coupled structural-acoustic formulation of problem in which the solution for structural and acoustic responses are obtained using simultaneous solution of two problems rather than solving them in a sequential manner as performed in uncoupled analysis. In this case, the equations for the structure, in the presence of both which are the force due to the acoustic pressure and the structural excitation can be written as,

$$[\mathrm{M_s}]\{\ddot{U}\}+[\mathrm{C_s}]\{\dot{U}\}+[\mathrm{K_s}]\{U\}=[\mathrm{A}]\{P\}+\{F_s\} \quad \textbf{(1)}$$

From the equation (1), $\{U\}$ is the structural displacement vector, $[\mathrm{M_s}]$, $[\mathrm{C_s}]$ and $[\mathrm{K_s}]$ are the structural mass, damping and stiffness matrices, respectively, and [A] is the structural-acoustic coupling matrix for the flexible surfaces of the system. Whilst to enable a prediction of sound field inside the enclosure, the equation (2) can be used to obtain the forced acoustic response to a structural and acoustic excitation. This equation can also be used to solve for the acoustic modes and frequencies of the cavity by taking the term on the right hand side to be zero and solving the eigenvalue problem based on that.

$$[\mathrm{M_a}]\{\ddot{p}\}+[\mathrm{D_a}]\{\dot{p}\}+[\mathrm{K_a}]\{p\}=-\rho[S]\cdot\{\ddot{U}\}+\{F_a\} \quad \textbf{(2)}$$

The acoustic excitation term $\{F_a\}$ has also been included on the right hand side and velocity term has been recast in the form of the acceleration of the boundary surface and various matrices have been renamed with subscript ‘a’ to indicate that they are associated with the fluid part of the system. Combining equation (1) and equation (2), we obtain an expression that is used to model the interaction between the fluid and the structure on the flexible surface as given below,

$$\begin{bmatrix}[\mathrm{M_s}] & 0\\ \rho[\mathrm{S}] & [\mathrm{M_a}]\end{bmatrix}\begin{Bmatrix}\ddot{U}\\ \ddot{p}\end{Bmatrix}+\begin{bmatrix}[\mathrm{C_s}] & 0\\ 0 & [\mathrm{D_a}]\end{bmatrix}\begin{Bmatrix}\dot{U}\\ \dot{p}\end{Bmatrix}+\begin{bmatrix}[\mathrm{K_s}] & -[\mathrm{A}]\\ 0 & [\mathrm{K_a}]\end{bmatrix}\begin{Bmatrix}U\\ p\end{Bmatrix}=\begin{Bmatrix}F_s\\ F_a\end{Bmatrix} \quad \textbf{(3)}$$

Thus, above equations give a simultaneous solution for structure and acoustic part and can be used to find structural and acoustic response to a structure and acoustic excitation [11].

III. DETAILS EXPERIMENTAL

3.1. Enclosure Model Prototyping

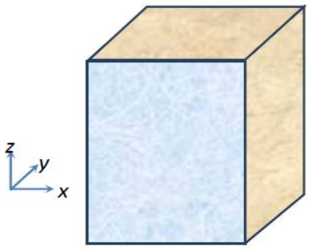

Figure 2. Enclosure Model Prototype

Materials / Parameters	Plywood	Aluminum Sheet Metal
Density (kg/mm^3)	592	7850
Poison ratio	0.3	0.32
Modulus of elasticity (Pa)	12.4×10^9	7.033×10^{10}
Thickness (mm)	7.5	0.16

Table 1: Material Properties of the Enclosure

In order to create a testing object for understanding structure borne-noise,an idea of prototype of enclosure is developed. The idea is to create anenclosure with a simplified geometry which is in rectangular shape. A thin plate of aluminum sheet metal held by the rigid body of plywood is used and acted as a source of structure noise once excitation is given on the surface.

Thus, experimental works for measuring both structure and noise of the enclosure can easily be done. Figure 2 shows the enclosure prototype to be used for the experimental works. The enclosure size *224* mm x *300* mm x *301.8* mm is made by joining of aluminum sheet metal at front surface while the sides, top, bottom and backside are made using plywood. Table 1 shows the material properties that have been used in the study material properties is very important because as the material properties is changed, the mode will change too [12].

3.2. Experimental Setup

Modal analysis and sound analysis are performed experimentally using LMS Spectral Testing. Experimental setup is shown in Figure 3 and Figure 4. The specific node on the developed enclosure is acoustically excited using shaker and as it vibrates the vibrational and sound responses are recorded by tri-axis accelerometer and microphone sensor respectively. Input parameter of the sensors is presented in Table 2.

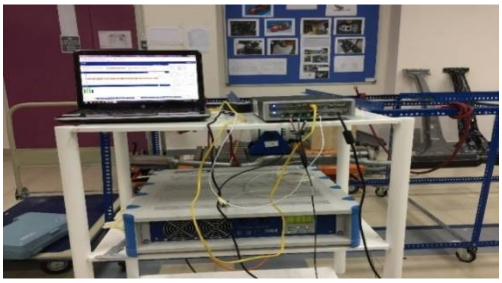

Figure 3. LMS Spectral Testing & Signal Processing

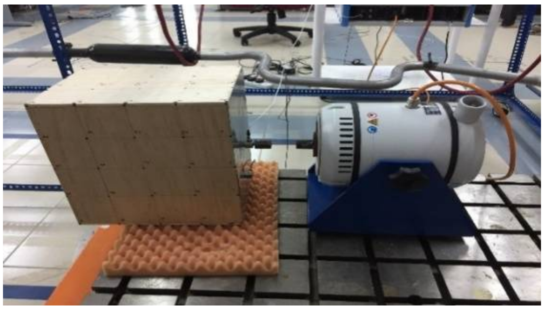

Figure 4. Shaker Excites the Enclosure Prototype

Sensor	Sensitivity			Output Measured
Tri-axis Accelerometer [mV/ms^{-2}]	x-axis: 10.42	y-axis: 10.43	z-axis: 10.58	Acceleration
Microphone [mV/Pa]	50			Pressure

Table 2: Input Parameter of Sensor

IV. RESULTS AND DISCUSSION

4.1. Natural Frequency

In order to verify the experimental set-up,natural frequency is firstly being compared. Experimental results show that, the total number of mode found is 11. The natural frequency extracted from the modal experiment is validated by the modal analysis performed in the simulation obtained from commercial software MSC NASTRAN/PATRAN. Comparison of the natural frequency is presented in Table 3. The percentage error ranges from 2.16 to 8.77 percent.

Number of mode	Modal Experiment [Hz]	Modal Analysis [Hz]	Percentage error [%]
1	13.17	13.74	4.33
2	24.74	22.93	7.32
3	30.80	33.50	8.77
4	41.06	40.03	2.51
5	43.34	42.13	2.81
6	59.61	58.32	2.16
7	64.86	66.35	2.30
8	69.11	67.82	2.76
9	75.54	77.69	2.85
10	82.72	84.97	2.72
11	91.05	93.57	2.77

Table 3:Comparison of Natural Frequency

4.2. Mode Shape

The normal modes of the enclosure is obtained from the experiment. In this paper, only first four mode shapes and the mode shape of the highest peak of vibration are illustrated in Figure 5 to Figure 9. The mode shape of the enclosure is bending mode shape.

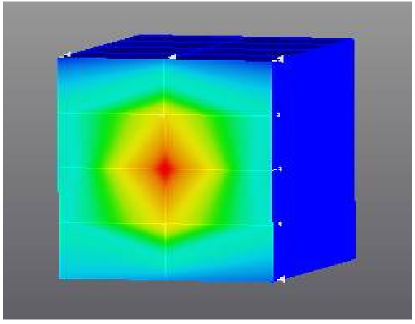

Figure 5.First Mode

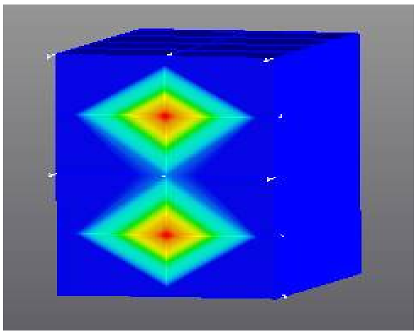

Figure 6.Second Mode

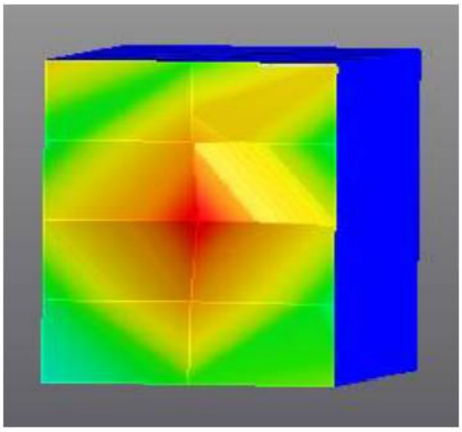

Figure 7.Third Mode

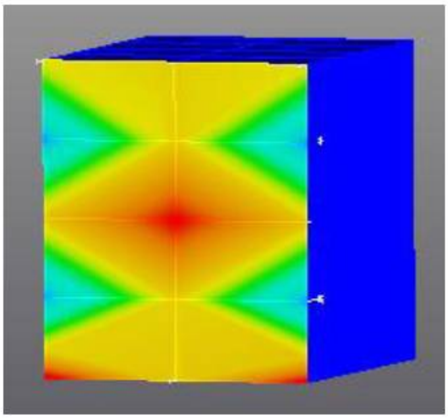

Figure 8. Fourth Mode

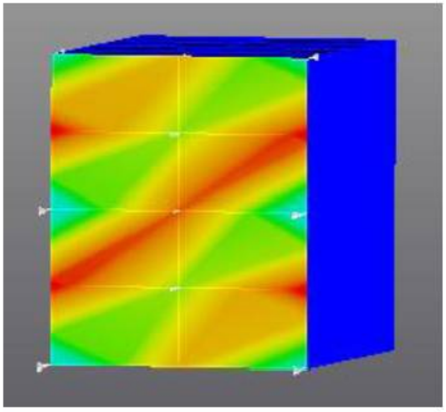

Figure 9. Sixth Mode (Highest Peak of Vibration)

4.2. Vibration & Sound Spectrum

From vibration spectrum, the highest peak is at frequency of 57.8 Hz while from graph of sound spectrum, the highest peak is at frequency of 60.6 Hz. As both the frequency of 57.8 Hz and 60.6 lied on the frequency range of mode number 6 as shown in Table 3, it is clearly found that, both maximum peaks of vibration and sound's spectrum are almost overlapping with each other at highest peak. Thus, from this point of view, the structure borne noise is extremely generated by the frequency at mode 6. Detailing and furthering studies are needed by shifting the resonance out from the desired range of studies so the frequency from vibration and sound spectrum would not be overlapping.

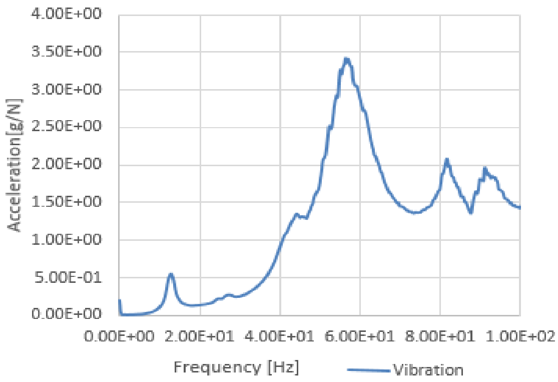

Figure 10. Vibration Spectrum

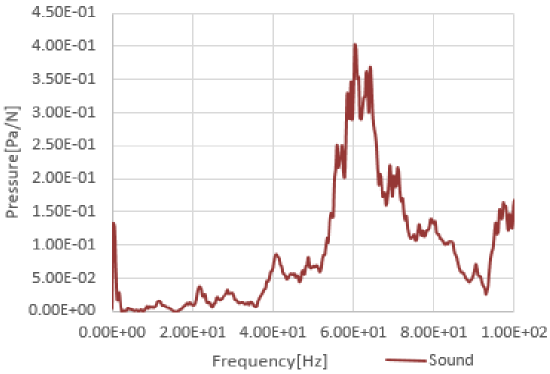

Figure 11. Noise Spectrum

CONCLUSION

In this paper, a study on structure borne-noise in an enclosure had been presented. Based on the studies some conclusion can be drawn. The idea of developed prototype enclosure is suitable for structure-borne noise analysis and it is found that both vibration and noise exists for further studies particularly for structure-borne noise analysis. The experimental and simulation of natural frequency result for this composite enclosure are in good term. The percentage errors are less than 10%.From the developed prototype, the structure behavior is successfully categorized which is the bending wave mode. The relationship between structure and noise of the enclosure are investigated and the frequency arealmost overlapping at maximum peak. Therefore, continuous improvement in analyzing the structure-borne noise is essential. In the future, author would like to improve the research by reducing the structure-borne noise in the enclosure developed

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