

VIBRATION CHARACTERISTICS OF LAMINATED COMPOSITE PLATES

MARY DIVYA FRANCIS¹ & BOBY JACOB²

¹PG Scholar, Computer Aided Structural Engineering, Department of Civil Engineering,
Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

²Assistant Professor, Department of Civil Engineering, Mar Athanasius College of Engineering,
Kothamangalam, Kerala, India

ABSTRACT

Laminated composite plates have been widely used in various industries such as aerospace, aircraft, automotive and audio because of their advantageous properties. Laminated composite plates used to fabricate structures or parts are in general joined together using flexible connectors or restrained by other structural components, which act as flexible supports to the plates. The free vibration characteristics (natural frequency and vibration shapes) of the elastically restrained laminated composite plates used in flat panel radiators are studied in this paper. The effects of layup and size of the composite plates on the modal characteristics and the natural frequencies are studied.

KEYWORDS: Composite Plate, Free Vibration, Modal Analysis

INTRODUCTION

Composite laminates are assemblies of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength and coefficient of thermal expansion. The individual layers consist of high-modulus, high strength fibers. Typical fibers used include graphite, glass, boron etc [1].

Lightweight structures made of composite materials are being increasingly used in many industrial fields for high-technology applications due to their versatile property profile. The specific combination of different materials in these function-integrating structures offers the possibility of synergistically fulfilling the requirements concerning the stiffness and strength as well as the damping and acoustic quality. Such novel lightweight structures are extremely sensitive to vibrations due to the much smaller forces of inertia, which leads to intense acoustic radiation.

The structural dynamic characteristics of lightweight materials such as fiber-reinforced polymers can show a complicated coupling of bending and torsion dependent on the fiber orientation, the matrix composition, and the lay-up.

Some of the instances where laminated composite plates are used are for the fabrication of aircraft structures in aerospace industry, vehicle parts in automotive industry and flat panel speakers in the audio industry. In general, laminated composite plates used to fabricate these structures/parts are joined together via flexible connectors or restrained by other structural components, which act as flexible supports to the plates. For aircraft and vehicle structures, the determination of the actual dynamic behavior of the flexibly supported plates in the structures is an important task if unwanted vibrations or noise radiated from the structures are to be suppressed. For laminated composite flat-panel speakers, it is also important to determine the actual dynamic properties of the flexibly supported laminated composite sound radiating plates of the

speakers if the generation of high-quality sound is desired.

In general, the motion of a flexibly supported plate consists of two parts, namely vertical rigid body motion and flexural vibration. The vertical rigid body motion contributes mainly to the sound radiation of the plate in the low-frequency range while the flexural vibration contributes to that in the mid to high frequency range. In designing a flat-panel speaker, since sound quality in the audible frequency range depends on the motion of the sound radiating plate, the determination of accurate modal characteristics of such plates is required.

FLAT PANEL SOUND RADIATOR

General

Elastically restrained laminated composite plates have been used to fabricate flat-panel sound radiators which can produce full range and high quality sounds. The elastically restrained laminated composite plates of these flat-panel sound radiators vibrate and radiate sounds when excited by an electro-magnetic exciter. The sound quality and radiation efficiency of the flat-panel sound radiators greatly depend on the vibration characteristics of the elastically restrained laminated composite plates. A thorough understanding of the vibration characteristics of the elastically restrained laminated composite plates can help improve the design of such flat panel sound radiators. On the other hand, the attainment of the actual vibration characteristics of elastically restrained composite plates can enrich the knowledge of the vibration analysis of composite plate structures. Therefore, the determination of accurate vibration characteristics of elastically restrained laminated composite plates is required.

Working of a Flat Panel Sound Radiator

The flat panel sound radiator mainly consists of a laminated composite plate, a flexible edge surround, an exciter and a rigid frame as shown in Figure 1.

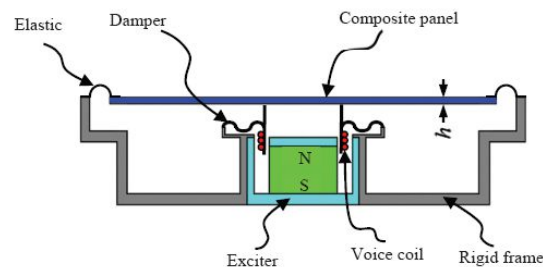


Figure 1: Components of a Flat Panel Sound Radiator

The rigid frame supports the exciter and the composite plate. The plate is excited at the centre by the exciter which causes the vibration of the plate which in turn helps in generating sound. The electromagnetic exciter consists of a cylindrical voice coil, a magnetic assembly and a damper. The voice coil is a cylindrical bobbin which is adhesively attached to the bottom of the composite plate. The bottom part of the bobbin is wound by a copper wire. When an electric current passes through the wire, the voice coil will move up and down to excite the plate. The flexible edge surround helps in restricting the vertical motion of the plate and the damper helps in restraining the vertical motion of the voice coil.

FINITE ELEMENT MODELLING

The modelling and analysis of the structure is done using the finite element analysis package ANSYS [4]. SHELL

91 elements are used to model the composite plate and the voice coil. SHELL91 may be used for layered applications of a structural shell model. The element has six degrees of freedom at each node: translation in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. The thickness of each ply and their orientations are defined. The length and thickness of the square laminated composite plates were 100mm and 0.6mm [2]. The radius of the voice coil assembly which is attached to the centre of the plate is 12.75mm. The height and thickness of the bobbin are 20mm and 0.15mm respectively. The diameter of the copper wire is 0.17mm and its winding height is taken as 6mm [3]. The material taken for the plate is graphite/epoxy. The material properties of the plate and voice coil are as given as:

Composite plate:

Young's modulus (longitudinal), $E_1 = 148\text{GPa}$

Young's modulus (transverse), $E_2 = 9\text{GPa}$

Shear modulus, $G_{12} = 7\text{GPa}$

Mass density, $\rho = 1269\text{ kg/m}^3$

Poisson's ratio, $\mu = 0.3$

Bobbin:

Young's modulus, $E_v = 65\text{GPa}$

Poisson's ratio, $\mu_v = 0.33$

Copper wire:

Young's modulus, $E_c = 101\text{GPa}$

Poisson's ratio, $\mu_c = 0.35$

The elastic edge surround is modelled as a spring system consisting of rotational and translational spring with constant spring intensities $K_R = .025\text{N}$ and $K_L = 7.5 \times 10^4\text{ N/m}^2$ respectively. The interior damper is modelled as a ring-type spring system consisting of translational springs of intensity $K_c = 1.3778 \times 10^4\text{ N/m}^2$. The springs are modelled using the COMBIN14 elements. COMBIN14 element has longitudinal or torsional capability in 1-D, 2-D, or 3-D applications. Figure 2 shows the model of a sound radiating plate with the voice coil attached to the centre of the panel.

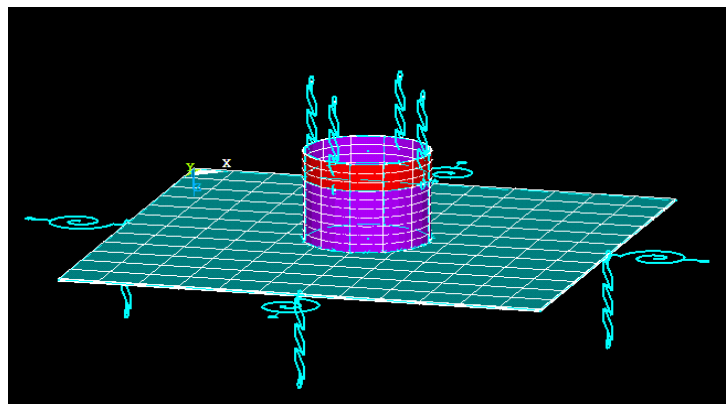
































Figure 2: Model of a Sound Radiating Plate

EFFECT OF PARAMETERS ON MODAL CHARACTERISTICS

Effect of Layup Sequence

To study the effect of the layup sequence on the modal characteristics of the plate, the modal analysis is done on a square laminated composite plate of panel dimension 0.1m x 0.1m. Table 1 shows the mode shapes associated with the first 10 natural frequencies of the flexibly restrained square plate for various layup sequences.

Table 1: Modal Characteristics of a Square Composite Plate with Different Layup

Layup	Modal Characteristics										
	Mode No	1	2	3	4	5	6	7	8	9	10
[90/0]s	Frequency (Hz)	186.1	194.7	201.5	219.6	399.1	523.01	681.4	705.6	834.02	894.5
	Mode shape										
[45/-45]s	Frequency (Hz)	189.5	205.7	228.6	263.5	453.3	531	536.4	766.2	922.6	963.6
	Mode shape										
[30/-30]s	Frequency (Hz)	184.49	201.34	219.1	249.4	402.2	507.7	596.3	693.8	816	867.6
	Mode shape										

The details of the plate modal characteristics are important in the design of flat panel speakers. Comparing the modal characteristics of the plate, from Table 1 it can be clearly seen that the modal characteristics of the laminated composite plates are totally different for each layup even with the same boundary conditions. This implies that the sound radiation properties of the laminated composite plates for each layup will be different for the same boundary conditions.































Regarding the plates under consideration there will be no contribution to sound radiation from the panel for the modes with nodal lines passing through the centre of the interior elastic support. This is because such modes with nodal lines passing through the centre will not be activated by the shaker.

Among the first 10 modes of the [90/0]s plate only the first, fifth and eighth modes of the plate can be activated by the shaker for sound radiation. In the case of the [45/-45]s plate the first, fourth, fifth, seventh and tenth modes will be activated for sound radiation. Similarly for the [30/-30]s plate modes 1, 4, 5, 7 and 10 is the sound radiating modes.

Effect of Panel Dimension

To study the effect of panel dimensions on the sound radiating properties of the plate three panels of different dimensions are considered. Panels of dimensions 0.05m x 0.05m, 0.1m x 0.1m and 0.15m x 0.15m are considered. Table 2 shows mode shape associated with the first 10 natural frequencies for different panel dimensions. The ply orientation for all the panels are taken as [90/0]s.

Table 2: Modal Characteristics for a [90/0] s Square Laminated Plate with Different Panel Dimensions

Panel Dimensions (m)	Modal Characteristics										
	Mode No	1	2	3	4	5	6	7	8	9	10
0.05x0.05	Frequency (Hz)	432.1	548.89	554.61	887.94	1392.6	1932.9	2561.3	2692.2	3474.6	3643.3
	Mode shape										
0.1x0.1	Frequency (Hz)	186.1	194.7	201.5	219.6	399.1	523.01	681.4	705.6	834.02	894.5
	Mode shape										
0.15x0.15	Frequency (Hz)	84.4	100.3	106.5	117	196.9	272	305.6	357	393.23	400.27
	Mode shape										

By comparing the modal characteristics from Table 2 it can be seen that the natural frequencies as well as the modal characteristics of the composite plate changes with change in panel dimension. It is noted that the natural frequencies decreases with the increase in panel dimensions. This is due to the increase in the mass of the panels with the increase of their size. For producing mid to high frequency sounds smaller panels can be used whereas for the production of sounds in the lower frequency the size of the panels has to be increased.

The mode shapes also change with the change in the panel dimensions even with the same boundary conditions. This implies that the sound radiation properties of the laminated composite plates for each panel dimension will be different for the same boundary conditions and layup.

As mentioned earlier the modes with nodal lines passing through the centre of the interior elastic support are not excited by the shaker and as a result there will be no contribution to sound radiation from these modes. In the case of the 0.05m x 0.05m panel the first, fifth, seventh and tenth modes are activated by the shaker for sound radiation. For the panel dimension of 0.15m x 0.15m only the third, fifth and eighth modes contribute to sound radiation.

CONCLUSIONS

A flat panel sound radiator has been modelled using ANSYS and the effect of the layup sequence and size of the panels in the sound radiation from the panels have been studied. The mode shapes are totally different for each layup sequence even with the same boundary conditions. Thus the sound radiated by each ply orientation will be different from that radiated by the other. There was not much change in the natural frequencies for the different layups.

The mode shapes as well as natural frequencies varied with the difference in panel dimensions. The natural frequencies decreased with the increase in panel dimensions. This is due to the increase in mass of the panel as the size increases. Hence to produce sounds of lower frequency larger panels have to be used.

The use of the composite plates in the design of flat panel speakers has been discussed. Also the importance of the modal characteristics of the composite plates has been discussed. The lower modes that are active in sound radiation of the laminated composite plates have been identified.

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