Journal of Sound and Vibration 408 (2017) 400–410

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Estimation of strains / stresses in composite panels using statistical energy analysis

K. Renji *, S. Josephine Kelvina Florence

Structures Group, ISRO Satellite Centre, Bangalore 560017, India

ARTICLE INFO

Article history:
Received 22 October 2016
Received in revised form
27 June 2017
Accepted 22 July 2017

Keywords:
Strain
Composites
SEA
Acoustic excitation

ABSTRACT

For the structural design of composite panels, subjected to acoustic excitation, the strains / stresses developed in the panel need to be estimated. In this work expressions for determining the strains / stresses in an SEA framework are derived. A typical composite panel used in spacecraft is subjected to diffuse field acoustic excitation in a reverberation chamber and the accelerations and the strains are measured. The strains are theoretically estimated using the expression derived and they match very well with the measured results.

1. Introduction

Honeycomb sandwich panels with composite face sheets are widely used in spacecraft. Among these elements the design of solar panels, reflectors etc., are governed by the acoustic loads due to their low value of mass per unit area. Therefore there is a need for a reliable prediction of their responses to acoustic excitation.

Responses of such systems at higher mode frequencies are normally estimated using Statistical Energy Analysis (SEA) developed by Lyon [1] and others. These calculations are later improved [2–5] and the improvements are then demonstrated for a plate [6]. Prediction of the responses for composite panels using SEA needed the determination of SEA parameters of such panels and these are also reported [7–9]. Inclusion of these expressions for the estimation of the SEA parameters has resulted in a reliable estimation of the acceleration responses [10].

In all the above works only the acceleration responses are discussed. But one needs to determine the stress / strain in order to verify whether the structure can survive the acoustic load. Though the acceleration responses are estimated reasonably well using SEA, the estimation of stress / strain in plates in an SEA framework when subjected to reverberant acoustic excitation are not well reported and hence carried out here.

In SEA, stress / strain are determined from the normal velocities. Lyon [1] had shown that the strains can be directly related to velocity response and had derived relationship among them for beams made of isotropic material. Norton and Fahy derived similar relations for simply supported isotropic plates and verified through experiments [11]. Karczub and Norton obtained such relations for the beams [12] and then for plates and cylindrical shells [13] for various boundary conditions and correlated with the experimental results. Finnveden and Pinnington [14] had shown the existence of such simple relationships between the strain and the velocities through a rigorous analysis. But no results are reported on the strains in composite panels when they are subjected to reverberant acoustic field [15].

* Corresponding author.
E-mail address: renji@isac.gov.in (k.Renji).

http://dx.doi.org/10.1016/j.jsv.2017.07.042
0022-460X/

Nomenclature

Symbols not listed here are used only at specific places and are explained wherever they occur.

A	area of a plate
h	thickness of the plate
a	acceleration response of a structure
c	speed of sound in air
D	flexural rigidity
D_{11}, D_{22}, D_{12}, D_{66}	Flexural rigidity values of composite panels
f	frequency, in Hz
p_i	acoustic pressure in subsystem i
V	Volume
v	velocity of a structure
v_{free}	velocity of the free wave
v_{forced}	velocity of the forced wave
η_d	dissipation loss factor
η_i	dissipation loss factor of subsystem i
η_{ij}	coupling loss factor for subsystem i to j
π_i	power input to subsystem i
ω	circular frequency, in rad/s
ρ	mass per unit area
ρ_a	density of the medium of the acoustic field
τ_r	random incidence sound power transmission coefficient of a structure
$\langle\rangle_{x,y}$	average over the domain x,y
$\langle\rangle$	*average over the time domain*
w	*normal displacement of the plate*
W	*amplitude of the normal displacement*

In this work, expressions that relate strain and stress in composite panels with the velocity are derived. A honeycomb sandwich panel with composite face sheets is subjected to diffused acoustic field in a reverberation chamber. The strains developed in the panels are measured. They are theoretically determined using the expressions derived here and compared with the measured strains.

2. Expressions for strain / stress

Dynamic response comprises of resonant and non-resonant parts. Therefore the strains / stresses generated also will have both resonant and non-resonant parts.

2.1. Strain response

Consider a plate as shown in Fig. 1. The coordinate axes x and y are in the plane of the plate and z is normal to the plate. The out of plane motion of the plate w can be represented by

$$w = We^{j(\omega t - k_x x - k_y y)} \tag{1}$$

where W is the amplitude of the normal displacement. k_x and k_y represent the wavenumbers in the x and y directions respectively. Therefore, $k_x = k\cos\theta; k_y = k\sin\theta$, where θ is the direction of wave propagation.

Strain at a distance z from the neutral axis is related to the normal displacement by

$$\varepsilon_x = -z\frac{\partial^2 w}{\partial x^2} \tag{2}$$

Substituting Eq. (1) in Eq. (2) and using the relation for velocity, $v = \frac{\partial w}{\partial t} = j\omega w$, the strain field at frequency ω in the surface of a plate having thickness h is

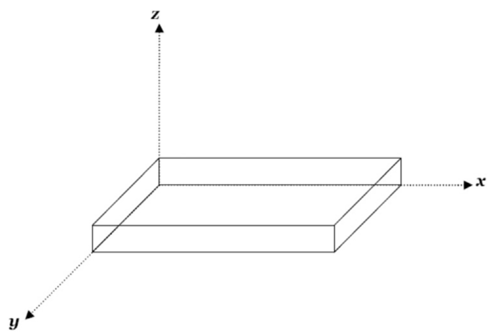

Fig. 1. Coordinate system of the plate.