Random vibration analysis of composite plate

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Abstract: Random vibration analysis is one of the major type of dynamic load which are having multiple amplitudes with multiple frequencies at a given particular time. The aerospace structure which contains Printed circuit board [PCB] fails frequently due to the high accelerations, high Stresses levels and high deformations under dynamic loads. So it is very important to analyse the PCB (Composite Plate) under dynamic load conditions. In the present research work, rectangular plate with composite materials which acts as PCB is analysed under random vibration load with different boundary conditions 2 faces fixed using Copper foil and Epoxy E Glass UD materials. The geometry of the rectangular plate is modelled in the FEA Software ANSYS. Proper fine mesh is done for the rectangular plate. Plate with [1/1], [2/2], [2/4] and [4/4] layups are designed in the Ansys ACP pre-module and later assigned the different properties of the composites to the rectangular plate and performed random vibration analysis by applying PSD G acceleration load to the fixed supports. A total number of 9 critical points are selected on the plate for calculating the PSD responses [Acceleration, displacement and normal stresses] to the random vibrations which are given to the rectangular plate. Based on the results, critical point is located and best material and best layup sequence is selected for the composite plate.

Keywords: FEA, Random vibration analysis, PSD and PSD Response.

Nomenclature: \( \rho \) = Density, \( E \) = Young’s Modulus, \( G \) = Shear Modulus & \( \mu \) = Poisson’s Ratio.

1. Introduction:
The structural loads can be classified in to two types based on the magnitude and direction with
respect to the time. If the load does not changes its magnitude and direction with respect to the given time, is called as static load. The failure comes under static load is called static failure. If the load changes its magnitude and direction with respect to the given time, is called as dynamic load. The failure comes under dynamic load is called fatigue failure. The structural loads can be classified in to several loads based on the time and frequency as illustrated in figure 1.

![Type of Loads Diagram]

**Figure 1** Type of Loads

Static Failure is gradual and fatigue failure is suddenly occur. The time and life of the static failure is more than the time and life of the fatigue failure. In reality pure cyclic loads very rare. In the lab we intentionally give the pure cyclic loads.

**Note:** In many real problems, it is found that exciting forces vary with time in a non-harmonic fashion that may be periodic or non-periodic.

Random vibrations are the loads having multiple amplitudes with multiple frequencies at the same time. These types of loads are frequency dependent. A seen pure sinusoidal vibration (harmonic) are having single amplitude with single frequency, but a random vibration loads are having multiple amplitudes with multiple frequencies. It is very difficult to define the random
load on a structure. The random vibration loads are converted into bins and then converted in to Power spectral density (PSD) input. The typical type of random vibration load and psd load are shown in the below figures 2.0 and figure 3.

![Random Vibration Load](image1)

**Figure 2 Random Vibration Load**

![Power Spectral Density](image2)

**Figure 3 PSD Load**

Karteek Navuri[1] performed random vibration analysis on the Flight data recorder (FDR) with ribs and without ribs, calculated PSD response at critical points using different types of isotropic and composite materials. Depend upon the PSD Response, best material for FDR is recommended. Wei Qu [2] calculated stress response to the random vibrations on the hydraulic composite pipe. Discrete type of analysis method for random vibration is used to solve the excitation of white noise. The results agreed with the simulation results, demonstrating that the analytical method could provide theoretical reference for the design, improved efficiency, and fatigue reduction of the composite pipe subjected to random vibration. Da Yu [3] concluded that the peak value of out-of-plane displacement of printed circuit board (PCB), when it is subjected to drop impact, is a major concern to electronic manufacturers as it relates to the maximum stress causing failure for the solder balls. M. A. Anuar [4] stated that, since the level of vibration always
depends on the natural frequencies of the system, it is important to know the modal parameters of such system to control failure and provide prevention actions. The demand for structurally reliable Printed Circuit Boards (PCB) has increased as more functions are required from electronic products along with less weight and smaller size. Jayaraman S [5] performed shock response spectrum analysis of printed circuit boards subjected to a half-sine pulse excitation using finite element method. The objective of this paper is to predict the shock response spectrum of a printed circuit board due to launch environment. The analysis results are validated by conducting experimental tests of PCB. Soma Shekar [6] uses basic FEA tool to accurately investigate the dynamic characteristics of the PCB and avoid costly testing methods which require hardware. Here the normal modes & frequency response functions (FRF) of PCB are determined and validated using vibration test on PCB. The validated model is used to predict vibration response for random vibration input. It is shown here how the responses are accurately predicted for random vibration input for a design parameter variation of PCB. The results are also validated using vibration test on PCB. Hanna Fahlhren [7] performed Modal analysis on the electronic unit. The result of the analysis shows that the first natural frequency of the chassis body and the PCB are not divided enough. During resonance coupling of acceleration are occurred. A rib design is developed to eliminate the coupling and to increase the first natural frequency of the bodies.

2. Problem Description:

2.1 Problem Statement

The main aim of the problem is to study the dynamic response of the rectangular composite plate under random vibration analysis using FEA software ANSYS.

2.2 Problem Modelling

The geometry of the rectangular plate is modelled in the ANSYS Workbench and respective dimensions with views are shown and in the below figure 4.0

![Dimensions of the Plate](image)

**Figure 4** Dimensions of the Plate

2.3 Materials

Copper foil and Epoxy Glass UD are used for the random vibration analysis. **Copper Foil:** $\rho = 8960$ kg/m$^3$, $E = 128000$, $\mu = 0.34$ and $\sigma_{yt} = 227$ MPa
Epoxy E Glass: $\rho = 8960$ kg/m$^3$, $E_{xy} = 45000$, $E_{yz} = 10000$, $E_{xz} = 10000$, $\mu_{xy} = 0.3$, $\mu_{yz} = 0.4$ $\mu_{zx} = 0.3$  
$G_{xy} = 5000$, $G_{xy} = 3846.2$ and $G_{xy} = 5000$

2.4 Mesh

Meshing is the process of converting geometry entities into the finite elements. Here quadrilateral elements i.e., Solid 186 Elements are used for the rectangular plate.

2.5. Loads & Boundary Conditions

The random vibration loads which are given to the rectangular plate are applied in the form base excitation i.e., PSD G acceleration is applied in the Y direction which is shown in the figure 5.0. The frequency range for the random vibrations is 0 to 2000 Hz. The boundary conditions are shown in the figure 6.0.

![PSD G Acceleration](image1)

**Figure 5** PSD G Acceleration

![Boundary Conditions](image2)

**Figure 6** Boundary Conditions

2.6 Composite Plate [PCB Board]

Now day’s three different types of PCB are used. Out of that FR4 PCB boards are used most commonly. In this research work, four types of layers are used i.e., FR4 single layer (1/1), FR4 multi layer (2/2), FR4 multi layer (2/4) and FR4 multi layer (4/4) with different fiber orientations.
2.7 Fiber Orientations

The fibres of the Epoxy E-Glass UD are oriented in many angles. The orientation of the fibers are shown in the below figure 8.0.
3 Random Vibration Analysis

The random vibration analysis on the composite plate are performed using above fiber orientations, list of results are calculated on the critical points which are shown in the below figure 9.0.

![Critical Points on the composite plate](image)

**Figure 9** Critical Points on the composite plate

It is recommended to conduct the modal analysis of the composite plate in between the range of minimum 1.5 times of the random vibration load frequency. The modal natural frequency range is 2500 because the random vibration load range is 1300 Hz. The natural frequencies of the composite plate (model 1) are listed in the below table 1.0.

| Mode No. | Frequency (Hz) |
|----------|----------------|
| 1        | 330.18         |
| 2        | 402.2          |
| 3        | 772.55         |
| 4        | 920.51         |
| 5        | 1027.1         |
| 6        | 1431.1         |
| 7        | 1627.4         |
| 8        | 1836.2         |
| 9        | 1961.1         |
| 10       | 2270.9         |
| 11       | 2409.3         |
From the above table, a total number of 11 natural frequencies are obtained in between the 0 to 2500 range. The first natural frequency is 330.18 Hz. The list of first six mode shapes of the composite plate are shown in the figure 10.0

![Figure 10: Mode Shapes of the Composite Plate](image)

The response PSD (Acceleration, Displacement and Normal Stress in Y direction) of the rectangular plate (Model 1) to PSD G Acceleration load is listed in the table 2.0.

**Table 2.0** Response PSD of the composite plate (Model 1)

| Point | Acceleration (m/s²) | Displacement (mm) | Normal Stress (MPa) |
|-------|---------------------|-------------------|---------------------|
| 1     | 133.3               | 0.38177           | 0.27653             |
| 2     | 1059.1              | 0.46281           | 1.211e-002          |
| 3     | 133.47              | 0.38163           | 0.72142             |
| 4     | 133.35              | 0.38168           | 0.49258             |
| 5     | 956.88              | 0.45015           | 8.6226e-003         |
| 6     | 133.33              | 0.38174           | 0.30892             |
| 7     | 133.42              | 0.38181           | 0.15304             |
| 8     | 1054.9              | 0.46225           | 1.3076e-002         |
| 9     | 133.43              | 0.38181           | 0.14824             |
From the above table it is observed that, the accelerations and displacements are maximum at the middle point of the free ends, the stresses are maximum at the fixed supports. The natural frequencies of the composite plate (model 2) are listed in the below table 3.

**Table 3 Natural Frequencies of the composite plate (Model 2)**

| Mode No. | Frequency (Hz) |
|----------|----------------|
| 1.       | 427.83         |
| 2.       | 584.96         |
| 3.       | 1184.1         |
| 4.       | 1347           |
| 5.       | 1415.8         |
| 6.       | 2239.1         |
| 7.       | 2340.4         |
| 8.       | 2601.1         |
| 9.       | 2997.3         |

From the above table, a total number of 9 natural frequencies are obtained in between the 0 to 2500 range. The first natural frequency is 427.83 Hz. The response PSD (Acceleration, Displacement and Normal Stress in Y direction) of the rectangular plate (Model 2) to PSD G Acceleration load is listed in the table 4.0.

**Table 4 Response PSD of the composite plate (Model 2)**

| Point | Acceleration (m/s²) | Displacement (mm) | Normal Stress (MPa) |
|-------|---------------------|-------------------|---------------------|
| 1     | 133.64              | 0.38428           | 2.6524              |
| 2     | 1219.6              | 0.42573           | 2.2442e-002         |
| 3     | 133.62              | 0.3842            | 6.7648              |
| 4     | 133.59              | 0.38423           | 4.8845              |
| 5     | 1078.5              | 0.41779           | 7.3861e-002         |
| 6     | 133.69              | 0.38427           | 3.0725              |
| 7     | 133.82              | 0.3843            | 1.522               |
| 8     | 1215.4              | 0.42548           | 2.0605e-002         |
| 9     | 133.81              | 0.3843            | 1.4608              |
From the above table it is observed that, the accelerations and displacements are maximum at the middle point of the free ends, the stresses are maximum at the fixed supports. The natural frequencies of the composite plate (Model 3) are listed in the below table 5.

Table 5 Natural Frequencies of the composite plate (Model 3)

| Mode No. | Frequency (Hz) |
|----------|---------------|
| 1.       | 427.96        |
| 2.       | 585.21        |
| 3.       | 1184.4        |
| 4.       | 1347.6        |
| 5.       | 1416.3        |
| 6.       | 2240.2        |
| 7.       | 2341.1        |
| 8.       | 2602.         |
| 9.       | 2998.5        |

From the above table, a total number of 9 natural frequencies are obtained in between the 0 to 2500 range. The first natural frequency is 427.96 Hz. The response PSD (Acceleration, Displacement and Normal Stress in Y direction) of the rectangular plate (Model 3) to PSD G Acceleration load is listed in the table 6.

Table 6 Response PSD of the composite plate (Model 3)

| Point | Acceleration (m/s²) | Displacement (mm) | Normal Stress (MPa) |
|-------|---------------------|-------------------|---------------------|
| 1     | 133.64              | 0.38429           | 2.6526              |
| 2     | 1219.9              | 0.42571           | 2.2389e-002         |
| 3     | 133.62              | 0.38421           | 6.7545              |
| 4     | 133.59              | 0.38424           | 4.8815              |
| 5     | 1078.6              | 0.41777           | 7.3795e-002         |
| 6     | 133.69              | 0.38428           | 3.0707              |
| 7     | 133.82              | 0.38431           | 1.5205              |
| 8     | 1215.7              | 0.42546           | 2.0597e-002         |
| 9     | 133.81              | 0.38431           | 1.4609              |
From the above table it is observed that, the accelerations and displacements are maximum at the middle point of the free ends, the stresses are maximum at the fixed supports. The natural frequencies of the composite plate (Model 4) are listed in the below table 7.

### Table 7 Natural Frequencies of the composite plate (Model 4)

| Mode No. | Frequency (Hz) |
|----------|----------------|
| 1.       | 366.87         |
| 2.       | 510.54         |
| 3.       | 1020.7         |
| 4.       | 1174.2         |
| 5.       | 1235.5         |
| 6.       | 1975.2         |
| 7.       | 2031.4         |
| 8.       | 2277.6         |
| 9.       | 2607.6         |

From the above table, a total number of 11 natural frequencies are obtained in between the 0 to 2500 range. The first natural frequency is 336.87 Hz. The response PSD (Acceleration, Displacement and Normal Stress in Y direction) of the rectangular plate (Model 4) to PSD G Acceleration load is listed in the table 8.

### Table 8 Response PSD of the composite plate (Model 4)

| Point | Acceleration (m/s²) | Displacement (mm) | Normal Stress (MPa) |
|-------|---------------------|-------------------|---------------------|
| 1     | 133.41              | 0.38542           | 3.9617              |
| 2     | 1131.8              | 0.44793           | 1.946e-002          |
| 3     | 133.59              | 0.38531           | 10.079              |
| 4     | 133.48              | 0.38535           | 7.2279              |
| 5     | 1000.1              | 0.43603           | 0.11256             |
| 6     | 133.47              | 0.3854            | 4.5454              |
| 7     | 133.52              | 0.38545           | 2.2616              |
| 8     | 1127.9              | 0.44755           | 1.3612e-002         |
| 9     | 133.52              | 0.38544           | 2.1809              |
From the above table it is observed that, the accelerations and displacements are maximum at the middle point of the free ends, the stresses are maximum at the fixed supports.

4. Conclusions:

Random vibration analysis is performed on the composite plate with different lamina sequence and orientations. PSD Response (Acceleration, Displacement and Normal Stress) are calculated using FEA Software. The list of observations and conclusions are made

1. The natural frequencies of the composite plate are higher with model 3.
2. Accelerations are maximum at the middle point of the free edges and less accelerations are obtained in the composite plate with model 1.
3. Directional displacements are maximum at the middle point of the free edges and less deformations are obtained in the composite plate with model 3.
4. Normal stresses are maximum at the free edges and less Normal stresses are obtained in the composite plate with model 1.
5. Out of the three results (Accelerations, displacements and Stresses), Acceleration magnitudes are considerable and it is recommended to use model 1 type for PCB boards based upon the random vibrations.

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