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Vibration Analysis of Printed Circuit Board Plate with Varying Boundary Conditions

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Abstract

Objectives: The Young's Modulus (E) plays key role in the vibration response of any structure. Hence its estimate with reasonable accuracy is of paramount importance. The Printed Circuit Board (PCB) used in military application consists of more than 6 layers, with pre-peg and copper composition. **Methods/Statistical Analysis:** The multiple layers PCB E value will vary from one design to other as it depends on the composition of layers. These PCB plates are subjected to vibration loads – sine, random and shock. A detailed work has been carried out to quantify the mechanical property of Young's Modulus (E) of the PCB plate both analytically and experimentally. **Findings:** This E value obtained was used in the FEM analysis (using ANSYS 16) to solve the vibration response of the PCB. The study also includes analytical calculation and experimental estimation of natural frequency of the PCB plate for different boundary conditions. The natural frequency estimation through analytical and experimental methods show good correlation thus validating the estimation procedure of E of the PCB as well. **Application:** This work gives us a robust method for estimating Young's modulus of Multi-layer PCB which find application in variety of military electronics.

Keywords: ANSYS, Natural Frequency, PCB Vibration, Random Vibration, Young's Modulus

1. Introduction

The PCB plate[1] is subjected to the random vibration spectrum from 10 Hz to 2000 Hz. It is necessary to estimate the natural frequency of the PCB. For this estimate, one has to have an accurate estimate of E value of the PCB. PCBs are designed and manufactured with a variety of polyamide materials such as solder mask, metallic material such as copper trace[2], composite materials[3] such as pre-preg and core material. For military application the PCBs are made up of different layers of copper which plays important role in the thermo-mechanical behaviour of the substrate due to the large Young's modulus of copper at both room temperature and reflow temperature. In this paper the estimation of E of PCB and using that estimation of natural frequency of PCB was carried out both analytically and experimentally to provide safe mounting design of the PCB in the military electronic assemblies.

2. Methodology

2.1 Young's Modulus Quantification – Analytical and Experimental

For calculating the E of the PCB plate by analytical, the direct copper traces data has been taken from ORCAD software from the PCB Design in the form of sizes/volumes (length-breadth-thick) and converted into percentage of copper. The relative percentage volume data is used to analytically estimate the E. FR-4 is the PCB material used for the study. The actual PCB was then subjected to tensile testing (Figure.-1) to experimentally evaluate the E value. The following formulae used for estimating the E[4]The clamping of the PCB during tensile testing is shown in Figure.-2.

The thickness ($T_i$in m) and percentage (P_i) of copper of each layer was taken into consideration for calculating the total volume of copper ($V_C$in m³) of the PCB is as follows

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$$V_C = \sum_{i=1}^{n} A_{PCB} * T_i * P_i$$ Where A_{PCB} is in m^2

Young's modulus of PCBs (**E_{PCB}**) was calculated from the stiffness of the two composing materials [2] and their material fraction.

$$E_{PCB} = E_{FR4} * \left(\frac{V_{PCB} - V_C}{V_{PCB}} \right) + E_C * \left(\frac{V_C}{V_{PCB}} \right)$$

Area of PCB=6.77E-03 m^2

Thickness of Each layer=7.00E-05 m

% of Copper in each layer

L1= 9.0220153; L2= 49.216928; L3=8.805045; L4=12; L5=26.3; L6=9.507097 (As per Electronic ORCAD data)

V_{PCB} = A_{PCB} * **T_{PCB}** =6.77E-03*0.00156=**1.06E-05** m^3

Vc = 5.45E-07 m^3

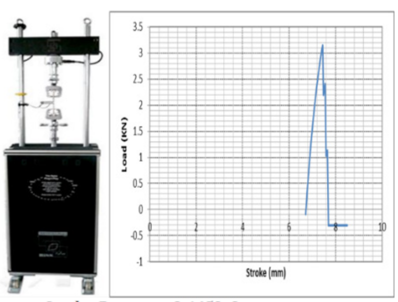
E_{FR-4} =1.86E+10 N/m^2

E_c =1.08E+11 N/m^2

E_{PCB} =2.32E+10N/m^2

Mass of PCB=0.019 kg

Density of PCB=1797.951 kg/m^3



$$\sigma = \frac{\text{Load}}{\text{Area}} = \frac{P}{A} = \epsilon E = \frac{3.1459e3}{21.74e-6} = 0.00627 * \text{Epcb}$$

Figure 1. Experimental Estimation of E for PCB.

Figure 2. Testing of PCB using UTM.

2.2 Experimental Estimation of 'E'

Strength properties of a PCB are determined by experimental method on NANO UTM at IISc, Bangalore. For calculating the E the PCB is subjected to tensile test as shown in Figure.1. The specifications of UTM are as mentioned below.

Load capacity: 25KN

Stroke length: 200mm

Types of loads induced: Tensile.

After the loading of the sample (PCB) in UTM till fracture, the graph gives the peak load thus estimating the stress induced (σ). Also the strain induced in the component is obtained by the difference between maximum stroke and minimum stroke value as shown in the graph as change in length (δl). Strain (ε) is be determined by formula ratio of change in length to original length. By having the values of stress and strain one can find the value of Young's modulus by the formula, E = σ/ε.

Calculations to find Young's modulus of component

From the tensile test experiment we found the following data,

l_1= Initial elongation=6.7261X10^{-3}m,

l_2=Final elongation=7.4416X10^{-3}m,

L=Original length =0.114m,

Fracture Load=3.1459X10^3N,

Area of PCB plate=21.74X$10^{-6}$$m^2$.

The experiment data is used to calculate the young's modulus of the PCB plate, which is found from experiment E_{PCB}=2.311X10^{10} N/m^2.

3. Natural Frequency Estimation

3.1 Analytical:

The natural frequency of the PCB under consideration was estimated analytically[5] as follows,

$$f_n = \frac{\pi}{2}\sqrt{D/\rho}\left(\frac{1}{a^2}+\frac{1}{b^2}\right) where$$

$$D = \frac{Et^3}{12(1-\upsilon^2)}; a, b \, and \, t \, are \, geometry$$

E=23 GPa; Density (ρ) = 1797.951 kg/m^3; Poisson's Ratio (υ) = 0.346

3.2 FEM Analysis

The PCB was modelled in ANSYS 16 to carry out modal analysis (using Block Lanczos Solver) for finding out the natural frequency of the PCB. The PCB with 4 holes mounted and 6 holes mounted boundary conditions were analysed and as expected the 6 hole mounted condition yielded higher natural frequency as shown in Figure.-3.

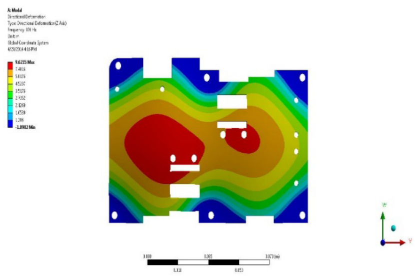


Figure 3. Modal Analysis with 6 point Mounting.

3.3 Experimental

A fixture was designed to mount the PCB on to the vibration shaker[6]. The fixture design was carried out with the consideration that the natural frequency of the fixture (3210 Hz) is well above the maximum frequency (2000 Hz) of the test spectrum. The PCB was mounted on the shaker and the response of the PCB was measured using piezoelectric accelerometer as shown Figure.-4. The peak amplification of the accelerometer output provided the estimate of the natural frequency of the PCB as evident from Figure.-5.

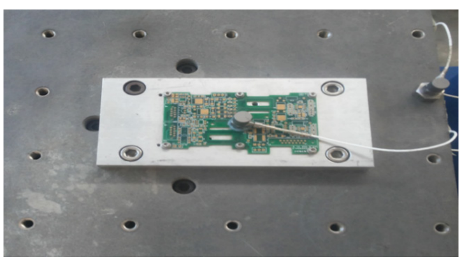


Figure 4. Modal Testing with 6 point Mounting.

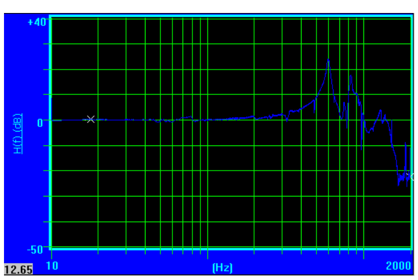


Figure 5. Response of PCB during Modal Testing.

4. Results

The Young's Modulus of the PCB was estimated and the same was used to predict the natural frequency of the PCB. The results of the work are summarized in the Table -1.

Table 1. Summary of Results

Estimation of Young's Modulus (GPA)				
Analytical	Experimental			Error %
23.2	22			1
Estimation of Natural frequency (Hz)				
Analytical	**FEM Analysis**		**Exp.**	**Error %**
	4 Holes mounted	6 Holes mounted		
605	310	876	830	-5.54

5. Conclusion

A composite structure of PCB plate (copper with FRP) was studied for its response to vibration. The Young's Modulus (E) for vibration analysis was estimated both analytically and experimentally (with very good correlation). These properties were used to predict the natural frequency of the PCB plate – analytical, FEM analysis and experimental. The FEM analysis and experimental values showed very good correlation. The analytical estimate differed from the other 2 estimates as the boundary condition of bolts at discrete places could not be modelled in the analytical method accurately.

6. References

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