Determination of Mechanical Properties of PCB

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Abstract: - PCB (Printed Circuit Board) is widely used in various engineering applications. PCB mechanically supports and electrically connects electronic components. To check the failure of component on PCB, it is important to perform PCB simulation for various load conditions. PCB construction varies with the number of component on PCB and criticality of circuit. Hence, material properties also changed according to type of PCB. In this paper, the importance of material properties in PCB analysis is discussed and Effect of material property variation on PCB response is studied. Based on these studies, critical material parameter of PCB is decided. PCB is fabricated by incorporating copper layers in sequence with FRP (fiber reinforced polymer) composite layer, for the purpose of forming conducting circuit. CLT (Classical Lamination Theory) is used to find the material properties of FRP laminate in PCB. Average properties of PCB material are determined by force balance equation. PCB properties are validated by simulation in ANSYS® and Sherlock® software's. Based on this knowledge, a programmed is developed to determine material properties of any PCB.

Keywords: - Classical Lamination Theory, Composite material, Natural frequency, Orthotropic material, PCB.

I. INTRODUCTION

For modern electronics, such as smart phones or other consumer electronics, improvement goals are much smaller scale, increased power, tougher durability, and more cost effectiveness. Electronic circuits in industry are normally manufactured through the use of PCB. The boards are made from glass reinforced plastic with copper tracks in the place of wires. Components are fixed in position by drilling holes through the board, locating the components and then soldering them in place. The copper tracks link the components together, forming a circuit. For mounting the electrical components on the printed circuit boards, an assembly process is required. This process can be done by hand or through specialized machinery. The assembly process requires the use of solder joint to place the components on the board.

PCB's are constructed according to the number of component's to mount on it. Depending on the number of planes or layers of wiring, which constitute the total wiring assembly or structures the PCB's can be classified in following three types [2] [3] [4]:- I. Single sided board: - means wiring is available only on one side of the insulating substrate where component are mounted only on one side of board, it is used in simple circuits. [2][3] II. Double Sided Board: - Double-sided PCBs have wiring patterns on both sides of the insulating material, i.e. the circuit pattern is available both on the components side and the solder side. Obviously, the component density and the conductor lines are higher than the single-sided boards. [2] [3] III. Multilayer Board: - A multilayer PCB board (Fig.1) is used in situations where the density of connections needed is too high to be handled by two layers or where there are other reasons such as accurate control of line impedances or for earth screening. The multi-layer board makes use of more than two PCBs with a thin layer of what is known as 'prepreg' material placed between each layer, thus making a sandwich assembly. Advantages of multilayer PCBs include high reliability and uniform wiring. However, the initial costs are higher than that of one-layered PCBs. Also, repairing a multilayer PCB is quite difficult. [2] [3]

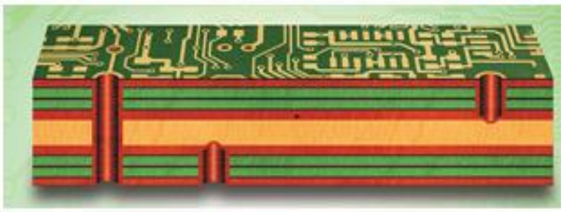

Fig. 1: Multilayer PCB (Printed Circuit Board)

II. PCB MATERIAL AND CRITICAL MATERIAL PROPERTY

A. PCB Material

A basic PCB starts with a copper-clad fibreglass material or thin copper sheets adhered to either side of the board. Fig. 2 shows the details of PCB internal structure. [6]

Core material is a rigid sheet of fiberglass resin material that has two sheets of copper adhered to either side. Some material may have a copper sheet on only one side. The copper is measured in ounces (oz). PCB manufacturers will refer to the copper thickness in ounces, but during board lay-up, or when the materials are stacked together, the inch/mm thickness is used. Pre-Preg material is made of similar material as the core material but is in a soft, pliable form and comes in standard-sized thin sheets. Copper foil is a thin sheet of copper that is placed on or between Pre-Preg materials and bonds to the Pre-Preg with the adhesive that is part of the Pre-Preg. [2] [3]

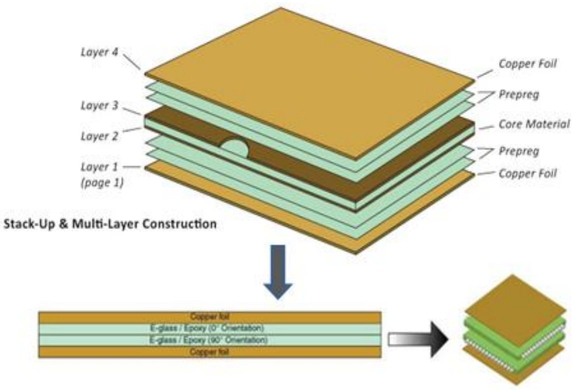

Fig. 2: Layers within the PCB

It is orthotropic material which requires nine elastic constant (E_x, E_y, E_z, G_{xy}, G_{xz}, G_{yz}, ν_{xy}, ν_{xz}, ν_{yz}) to specify the material. In more detail, it is composite laminate Fig. 1 containing two or more different types of materials (FR4 and Copper) called as hybrid composites and, more specifically interply hybrid composites. [5] Material Properties of PCB depend on the properties of composite laminate and copper. [7]

B. Critical Material Property

Stress analysis requires nine material properties but it is not always possible to have all nine properties with correct experimental value. There might be one or more out of nine, which is critical parameter and will most affect the analysis results. To get that critical material parameter number of analysis are performed to check the variation. Therefore, this paper is dedicated to study the effect of material properties on PCB response.

Variation effect of in-plane modulus E_x and E_y is not considered because correct values of laminate are generally given by manufacturer. While, values of remaining properties of laminate are not available. So, the modal analysis in ANSYS® with varying values of (E_z, G_{xy}, G_{xz}, G_{yz}, ν_{xy}, ν_{xz}, ν_{yz}) and see the variation of natural frequency with respective parameter for same geometry bolted at corner and center .

The geometry on which these analyses are performed is as shown below in Fig. 3. Here, internal surface of the mount hole is made fixed for all analysis. Total 70 such analyses are performed to get frequency response for assumed properties.

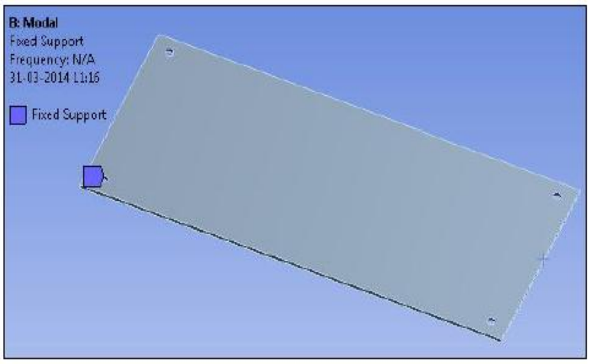

Fig. 3: PCB Geometry

For getting the variation of Natural frequency with E_z, all properties are kept fixed and E_z is varied 10 times from 3GPa to 12GPa as shown in Table.1 Results of first mode natural frequency Vs E_z are plotted and discussed in Fig. 4

Table 1: Material Properties with varying E_z values

MTL	GPa									Kg/m3
No.	Ex	Ey	Ez	Gxy	Gyz	Gxz	Vxy	Vyz	Vxz	Density
11	19	23	3	1.97	1.97	1.97	0.1	0.38	0.4	1900
12	19	23	4	1.97	1.97	1.97	0.1	0.38	0.4	1900
13	19	23	5	1.97	1.97	1.97	0.1	0.38	0.4	1900
14	19	23	6	1.97	1.97	1.97	0.1	0.38	0.4	1900
15	19	23	7	1.97	1.97	1.97	0.1	0.38	0.4	1900
16	19	23	8	1.97	1.97	1.97	0.1	0.38	0.4	1900
17	19	23	9	1.97	1.97	1.97	0.1	0.38	0.4	1900
18	19	23	10	1.97	1.97	1.97	0.1	0.38	0.4	1900
19	19	23	11	1.97	1.97	1.97	0.1	0.38	0.4	1900
20	19	23	12	1.97	1.97	1.97	0.1	0.38	0.4	1900

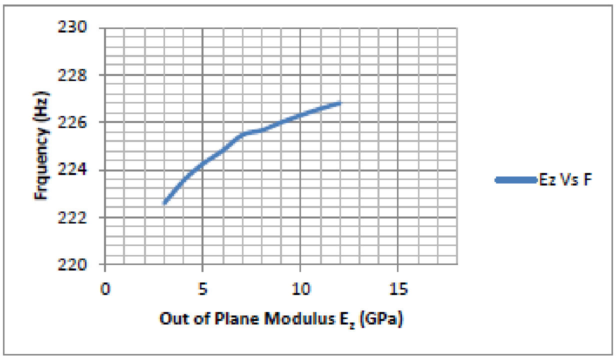

Fig. 4: Out of Plane Modulus Ez Vs Natural Frequency

From Fig. 4 it is clear that variation of E_z does not cause large variation in natural frequency.

Similarly, analyses are performed to get the variation of natural frequency with ν_{xy}, ν_{xz} and ν_{yz}. Fig. 5 Shows the results of respective analysis:-

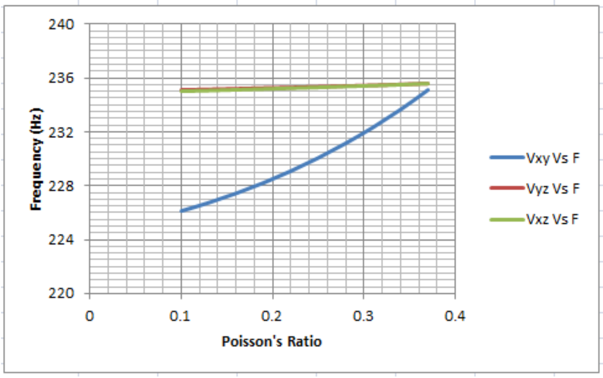

Fig. 5: Poisson's Ratio Vs Natural Frequency

From above graph in Fig. 5, it is clear that variation of Poisson's ratio does not cause large variation in natural frequency. But, In-plane Poisson's ratio ν_{xy} shows larger variation than ν_{xz} and ν_{yz}.

Similarly, analyses are performed to get the variation of natural frequency with G_{xy}, G_{xz} and G_{yz}, Fig. 6 Shows the results of respective analysis:-

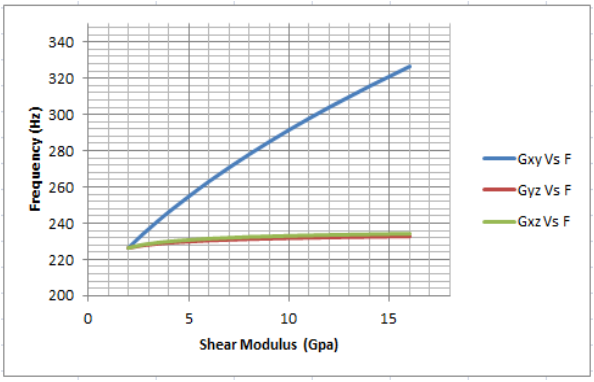

Fig. 6: Shear Modulus Vs Natural Frequency

Variation of G_{xy} property shows larger variation in natural frequency response than all other properties considered for parametric analysis. Therefore it is concluded that, G_{xy} is critical material parameter of PCB. It is important to find the fairly accurate value of G_{xy}. It is noted that third direction property is not playing any role in deciding the natural frequency of PCB. PCB shows plane stress condition if the total thickness is less than 6mm. [8] Therefore, CLT is used to determine material properties of FRP laminate. PCB properties are determined using force balance equations which use FRP and copper properties. [9] [5]

III. MATERIAL PROPERTY EVALUATION AND VALIDATION

A. Laminate Property Evaluation

As, it is clear from Fig.2 that PCB material property are depend on properties of copper and laminate. FRP laminate properties depends on it's constitute. That means fiber and epoxy. Therefore, properties are determined in sequence of lamina, laminate and PCB.

PCB Material Properties:-

= f (Composite Laminate, Copper)

Where

Composite Laminate:-

= f (Fiber, matrix (or epoxy))

Hence

PCB Material Properties:-

= f (Fiber, matrix (or epoxy), Copper)

Lamina properties are determined using rule of mixture for 50% volume fraction of glass fiber and epoxy matrix. Laminate consist of 0° and 90° orientation layers which is common for most of the PCB used in industry. [6] Programmed in Visual Basic® is developed to determine properties of laminate using CLT. Demo screen of programmed calculator is shown in Fig.7. [5] [10]

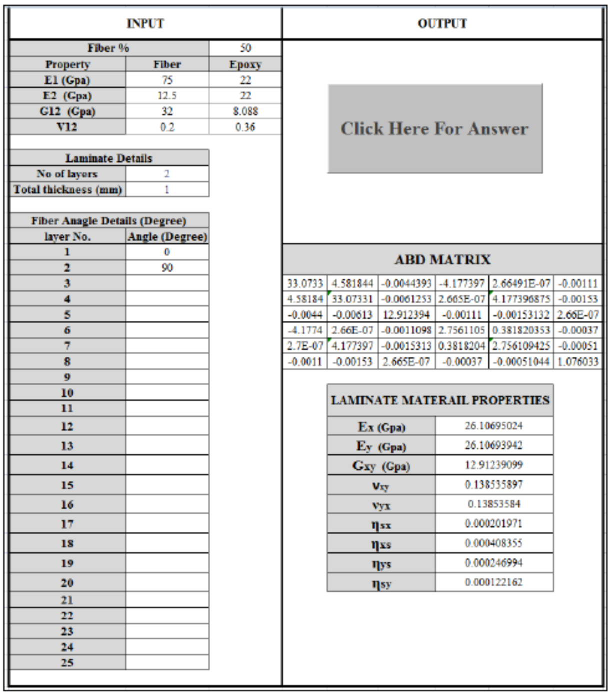

Fig. 7: Demo Screen of laminate calculator

B. Determination of PCB Properties

Once, laminate properties are determined based on the considered constitute. These laminate properties and copper properties are averaged to get PCB properties. PCB is generally specified by its copper layer thickness, number of copper layer and total thickness. [4] E.g. (1oz 4layer 1.6mm) means total thickness is 1.6mm; there are 4 copper layers each of thickness 1oz (0.035mm). General stack-up of PCB is as shown in Fig. 8, It shows multilayer PCB where four copper layers are used and they are stacked alternately with glass-epoxy laminate. [6]

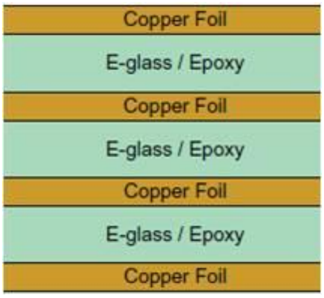

Fig. 8: Stack-up of PCB

Copper Properties depends on the percentage of copper spread. Formulae for PCB elastic Modulus in X and Y direction are obtained by equating force applied in those direction are equally shared by both material. Combined the deflection in Z-direction as sum of deflection produced in laminate and copper is used to determine modulus in Z-direction. Similar methodology is applied to get the shear modulus and poison's ratio in respective planes. A density formula is derived by equating the combined mass as a sum of individual mass of copper and laminate. [7] Sample derivation for modulus in X-direction is as shown below:-

$$\frac{A_{pcb} * E_x}{L_{pcb}} = \left(\frac{A_l * E_{xl}}{L_l} + \frac{A_c * E_c}{L_c}\right)$$

But, L_{pcb}=L_l=L_c= length along X-direction

A_{pcb} =h_{pcb}*b, A_l=h_l*b and A_c=h_c*b

So by combing this we get,

$$E_x = \left(\frac{h_c * E_c}{h_{pcb}} + \frac{(h_{pcb} - h_c) * E_{xl}}{h_{pcb}}\right) \quad (1)$$

Where, h_{pcb}= total thickness of PCB

h_c= (number of copper layer) X (thickness of one copper layer)

E_c= copper Young's modulus of elasticity

E_{xl}= laminate modulus in X-direction (calculated by CLT)

Similar procedure is followed for the evaluation of other properties and obtained formulae's are programmed in Visual- Basic® along with classical lamination theory. Demo screen of programmed calculator is as shown in Fig.9 [10]

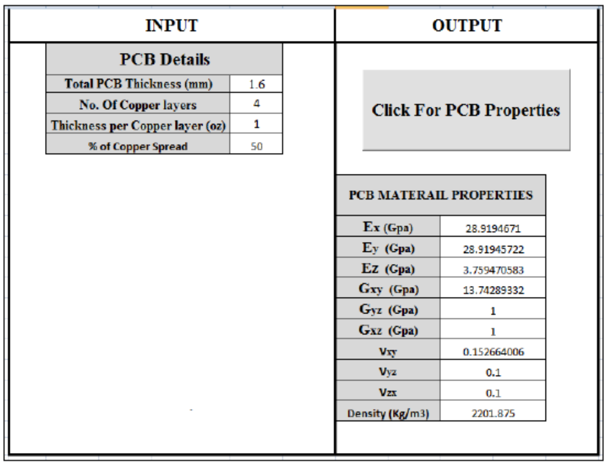

Fig. 9: Demo Screen of PCB calculator

Here, copper properties are function of percentage of copper spread. Constant values of G_{xz}, G_{yz}, E_z, ν_{yz} and ν_{xz} properties are considered because these properties have not shown considerable effects on natural frequency with their variation.

C. Property Validation by Sherlock® software

Properties mentioned in Fig.9 can be used for the any analysis of PCB. As PCB final analysis result is totally depend on the material properties, it is required to validate determined properties in Fig. 9. For this purpose the Sherlock® software is used. Sherlock® is specially used software for analysis of PCB's; it has its own material library according to the PCB construction and its constituents. [7] For validation, Modal analysis is performed in both the software for same geometry and results are compared.

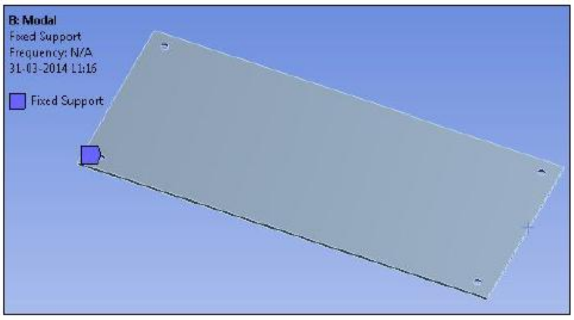

Fig. 10: PCB model

Geometry used in ANSYS® is PCB plate modeled in Creo® modeling software as shown in Fig. 10 which is bolted at four corners. Material properties assigned are orthotropic and as that of Fig.9

Modal analysis in ANSYS® is performed on above geometry and first five mode natural frequencies are found which are listed in Table.2

Stack-up is generated in Sherlock® with material selection same as that of used in ANSYS® and generated layers are as shown in Fig. 11

Layer	Type	Material	Thickness
1	SIGNAL	COPPER (50%) / COPPER-RESIN	1.0 oz
2	Laminate		19.1 mil
3	SIGNAL	COPPER (50%) / COPPER-RESIN	1.0 oz
4	Laminate		19.1 mil
5	SIGNAL	COPPER (50%) / COPPER-RESIN	1.0 oz
6	Laminate		19.1 mil
7	SIGNAL	COPPER (50%) / COPPER-RESIN	1.0 oz

Fig. 11: Sherlock® PCB Stack-up

Geometry used in Sherlock® is as shown in Fig. 12 where, dark spot shows the mount points same as that of bolt fixation in ANSYS®.

Modal analysis is performed in Sherlock® and first five natural frequencies were found and listed in Table. 2.

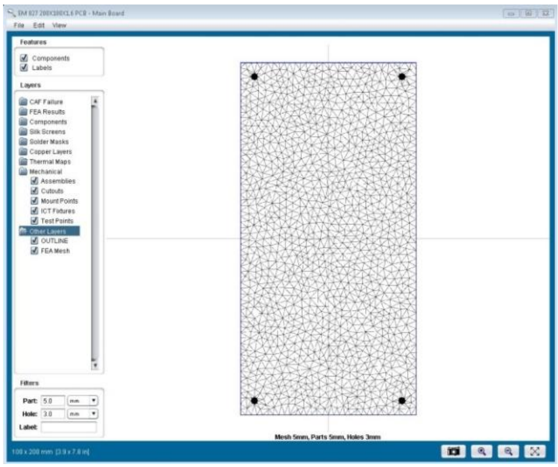

Fig. 12: Sherlock® geometry details

Results of above analysis are compared and there percentage difference is found as shown in Table. 3.

Table 2: Natural Frequency Validation Results

Mode	Natural Frequency (Hz)		% Diff.
	Ansys®	Sherlock®	
1	146.18	147.4	0.82
2	284.4	283.1	0.45
3	402.6	406.16	0.87
4	641.29	641.96	0.1
5	643.41	650.35	1

From Table 3, it is clear that all mode natural frequency is most nearly matched and fallow same pattern within 1% of difference.

IV. CONCLUSIONS

In this paper, PCB is studied in detailed. For selected PCB, major constructions type and material constituents are documented. General important considerations for PCB analysis are studied. As in material study it is found that, PCB is orthotropic material and it requires nine material properties to define the material. Modal analysis is performed in ANSYS® to find the effect of individual material properties on natural frequency of PCB and it is concluded that Gxy is a critical material property. As the thickness of PCB in very small, plane stress analysis is considered. Hence, CLT is used to determine material properties of FRP laminate in PCB. PCB properties are calculated by averaging FRP laminate and copper properties using force balance equations. The PCB material properties are used for modal analysis of PCB using ANSYS® and same properties are validated using Sherlock® software by considering same geometry model and inbuilt material database of Sherlock® software. The developed procedure/programmed can be used to determine material properties of any PCB, as procedure is validated with widely used Sherlock® software. Also, Developed programmed can be an alternative to costly Sherlock® software to derive material properties.

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