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Vibration Response Prediction of Printed Circuit Boards used in The Transportation Industry

The in-service vibrations that occur within a transport vehicle during operation can compromise its electronic systems, thus, decreasing the vehicle's reliability. Printed circuit boards (PCBs) and Printed Circuit Board Assemblies (PCBAs) predominantly experience failure due to such vibrations. The objective of this research was to select a best candidate material properties model for PCBs and PCBAs based on the dynamic response under various vibration excitations. The isotropic and orthotropic properties models of the PCBs available in the existing literature were numerically simulated using the finite element (FE) based tool and the obtained results were compared through direct experimentations, conducted in a bare PCB using the impulse hammer and a modal shaker. Comparisons of the responses between the theoretical and the experimental results showed that the theoretical orthotropic model of the PCB was close to the experimental model. In addition, the experimental results suggest that the modulus of elasticity of the PCBs varies across the lateral, longitudinal and vertical directions.

1. Introduction

When evaluating PCBs the observations must begin at the base level of the composition of the PCB itself. The specific composition that is evaluated in this research is a six-layer configuration with both isotropic and orthotropic mechanical properties. Testing the two different setups is crucial as the difference between isotropic and orthotropic shows the baseline behind why simulation of just an isotropic PCB (as done in most existing literature and industry) simply is not accurate enough to create a reliable baseline for later in the research due to the differences in the mechanical properties.

2. Simulation

For this project a large portion of the work to create the baseline values was done via harmonic simulation and was done through DSS Solidworks Simulations tool. The simulations specifically were linear harmonic tests. In total, eight of these tests were simulated to see the response of our 4 different models **[table 1]** of PCB which were found in existing literature in clamped-free and clamped-clamped configurations **[figures 1 & 2]**. Model 1 is the control for an isotropic PCB, this is being simulated to give a quick glimpse of how much the response of an isotropic PCB varies from multiple different orthotropic PCBs (Models 2, 3, & 4). The simulation portion of this experiment is of extreme importance as it shows how under perfect conditions the PCB should react. Models 2, 3, and 4 are used primarily to use as comparisons to relate with the experimental data to have a rough estimate of what the properties of the physical PCB are.

Material Property	Model 1 Isotropic	Model 2 Ortho 1	Model 3 Ortho 2	Model 4 Ortho 3
E_x (Pa)	1.50E+10	1.69E+10	1.90E+10	2.30E+10
E_y (Pa)	1.50E+10	1.69E+10	2.30E+10	1.90E+10
E_z (Pa)	1.50E+10	7.40E+09	4.00E+09	4.00E+09
G_{xy} (Pa)	5.30E+09	7.60E+09	1.97E+10	1.97E+10
G_{xz} (Pa)	5.30E+09	3.30E+09	1.97E+10	1.97E+10
G_{yz} (Pa)	5.30E+09	3.30E+09	1.97E+10	1.97E+10
ν_{xy}	0.39	0.11	0.1	0.1
ν_{xz}	0.39	0.39	0.4	0.4
ν_{yz}	0.39	0.39	0.38	0.38
Mass Density (kg/m^3)	1910	1910	1900	1900

Table 1: Mechanical Properties found in literature

3. Manufacturing

The manufacturing of this experiment was a huge component of the project as it had to be completely designed and built from scratch. The best option for material for the apparatus would be a solid metal like billet aluminum due to its known mechanical properties as well as it being one solid piece, but due to budget constraints it was decided to make the apparatus' components via 3D printer which used a PLA extrusion. This was convenient due to the relative ease of making changes if necessary and reprinting pieces if needed in a short time span. However, during experimentation of the physical PCB it was found that the PLA which has a Young's Modulus range of 0.05- which is low enough where the simulations and physical experimentation could be thrown off slightly. Also due to the large range the value picked for the stands in the simulation may not exactly match the material the physical apparatus is made of.

4. Experimentation

The experimentation for this project consists of two configurations one being a clamped-clamped configuration **[figure 1]**, and the second being clamped-free **[figure 2]**. The first test was used to find the natural frequencies of the physical PCB. This test used the modal hammer **[figure 3]** to test the response of the PCB through an impulse test which showed the response through a range of 0-500 Hz. The hammer tests were done for both the clamped-free and clamped-clamped configurations. For the second phase of experimentation the modal shaker was introduced to the testing apparatus **[figure 4]**. These tests were modal time history tests which were used take the natural frequencies found in the first experiments and applied a small range of frequencies around them to see the response of the PCB around the natural frequencies. This is done to have more precise dynamic responses of the PCB.

Figure 1: Clamped-Clamped Configuration

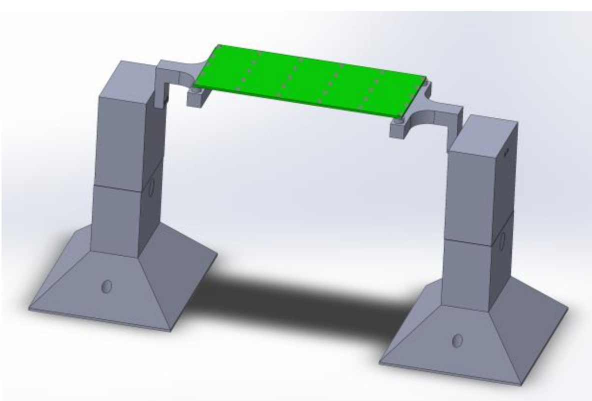


Figure 2: Clamped-Free Configuration

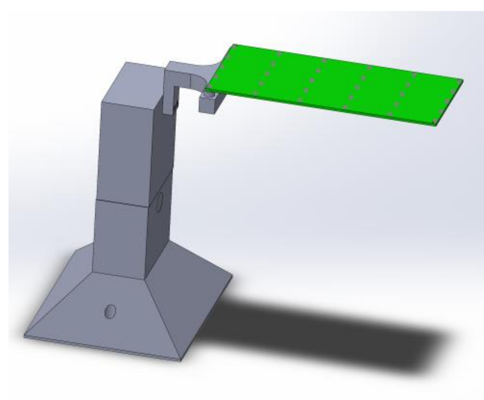


Figure 3: Impulse Hammer

Figure 4: Modal Shaker

5. Results

The first test done was the linear harmonic (hammer) tests during these tests the clamped-clamped configuration gave extremely consistent values that can be shown in Table 2. When testing the clamped-free configuration however the issues of sensitivity, and major feedback noise come into play which prevented the ability of getting solid frequency values. Due to the inconclusive testing to make up for it the modal testing for clamped-free had to be over wider ranges and were based off the simulation of Model 3 as it is so similar.

Table 2: Hammer Test Results

Experimental Natural Frequencies	
Linear Harmonic Tests	Clamped-Clamped (Hz)
Test 1	58.6
	82
	127
Test 2	58.6
	82
	127
Test 3	58.6
	82
	127

During the simulations of the four model PCBs the responses of all four can be seen in **[figures 5 & 6]**, but as the first natural frequencies had the largest response the focus of the experimentations went to the first natural frequency of the PCB. When viewing **[figures 7 & 8]** the relationship of Model 3 and the experimental results the mechanical properties of Model 3 became the benchmark values to relate as its first natural frequency was at 56.54 Hz with a response of 55.90 G in the clamped-clamped configuration and 17.65 Hz and a response of 30.93 G in the clamped-free configuration. These values most closely relate to the experimental data collected of 17.04 Hz and 28.32 G for clamped-free and 55.13 Hz and 54.79 G in the clamped-clamped setup. These results show the necessity of properly simulating a PCB as if it is not done it will drastically change the results to the point where the simulation is useless as it won't supply realistic data.

Figure 5: Total simulation response C-F

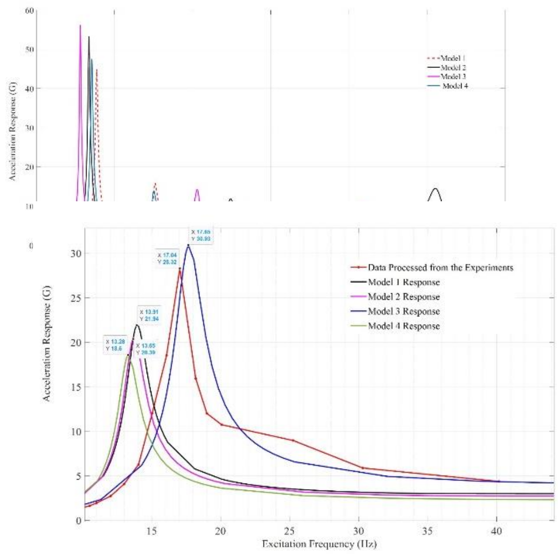
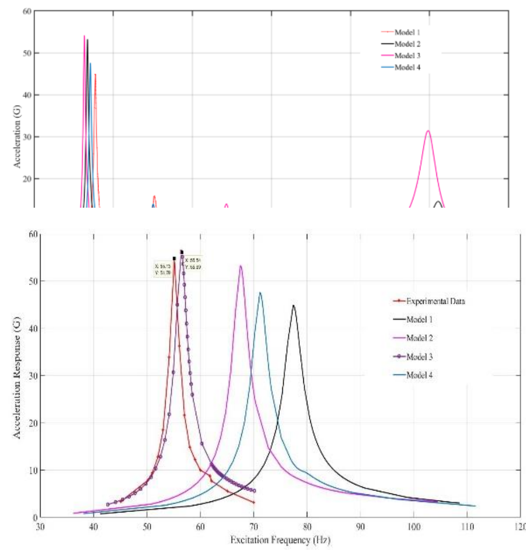


Figure 6: Total simulation response C-C



6. Conclusions

In the present work the dynamic responses of printed circuit boards have been examined with simulations and experimentation.

During the simulations and experimentations, the natural frequencies of 1 isotopic PCB and 4 orthotropic PCBs have been extracted and compared among one another to examine the relationships between each model. It has been determined that the dynamic responses and therefore the natural frequencies of an isotropic and orthotropic PCB do not match. This is due to the comparison of simulation and experiment showing a high degree of similarity between each other.

7. Future Works

The first of the future works will be compiling the responses of the physical experiments to determine the mechanical properties of the physical PCB to complete further research of the PCB. The next is to repeat this physical experimentation we did in the present works, but with a printed circuit board assembly (PCBA) to determine the differences on dynamic response due to the added mass. As the present work was done to see if simulating an isotropic PCB would be a valid option due to its simplicity;

the future work would be to determine if the increase in mass of a PCBA would warrant a large enough difference in dynamic behavior to warrant its own full simulation as opposed to simulating a bare PCB with the correct mechanical properties.

References:

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