MODELING OF DYNAMIC BEHAVIOR OF PRINTED CIRCUIT BOARD (PCB) SUBJECTED TO MECHANICAL SHOCK LOADING

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Dedicated to my country,

And

To my beloved father, mother and brothers.

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ABSTRACT

The reliability assessments of PCB and PCB related products had been adopted by industries for years. Among the reliability test, mechanical shock damage is one of the most predominant modes of failure when PCB experience deformation that creates excessive strain. For dynamic analysis, it is very expensive, time consuming and difficult to conduct drop/shock test to detect the damage mechanisms and identify their behaviors. However, this assessment can be performed through a computer simulation by Finite Element Method (FEM). FEM is one of such techniques to achieve solution within reasonable computational time and cost. This study presents dynamic analysis of PCB and PCB devices by FEM. As a fundamental study, the natural dynamic properties of a bare PCB and workstation chassis are obtained by FEM and verified with impact hammer test. Good agreement of natural frequencies and mode shapes had been shown between FEM and tested results. From the verified dynamic properties, the shock analysis was carried out further for PCB with components. Two different ways had been carried out. First, to model the drop impact behavior, the free-fall of PCB with attached chips was modeled for seven drop orientation. The bouncing motion was captured and the dynamic responses on all chips had been analyzed and had good agreement compared to reported research. The second impact analysis is done by simulate the PCB with chips that fixed on a drop block. To implement the input-G method, a short impulse was impose to the PCB fixture surface. The natural dynamic behavior was obtained for fixed boundary condition followed by detail deflection motion of PCB due to impact. The simulated result shows that the center of PCB experiences greatest impact, which is well verified with recent related research.

ABSTRAK

Pengukuran kebolehtahanan papan litar cetak (PCB) dan produk berkaitan telah lama diamalkan dalam industri. Antaranya, kerosakan kejutan mekanikal merupakan salah satu mod pradominan yang menyebabkan kerosakan pada PCB akibat terikan hasil daripada lenturan. Untuk analisa dinamik, adalah mahal, makan masa dan susah untuk menjalankan ujikaji bagi mengesan mekanisma kerosakan dan mengenali kelakuannya. Namun, pengukuran ini dapat dijalankan dengan simulasi komputer melalui Kaedah Unsur Terhingga (FEM). Ia merupakan salah satu teknik penyelesaian yang menggunakan perbelanjaan dan masa yang berpatutan. Kajian ini mempersembahkan analisa dinamik PCB melalui FEM. Sebagai kajian dasar, sifat getaran semulajadi pada PCB dan rangkanya telah dikaji dan disahkan dengan ujikaji hentaman tukul. Keputusan antara FEM dan ujikaji didapati bersetuju. Daripada keputusan tersebut, analisa kejutan dibuat dengan PCB berkomponen. Dua cara telah diperkenalkan. Pertamanya, untuk mengkaji kejutan jatuh, PCB berkomponen telah dimodel jatuh bebas pada tujuh arah yang berlainan. Pergerakan lonjakan dan tindak laku dinamik telah diperoleh dan setuju dengan perbandingan kajian lain. Cara kedua disimulasi dengan PCB berkomponen yang ditempatkan pada blok jatuh. Untuk mengimplikasi cara kemasukan-G, kejutan pantas telah dikenakan pada permukaan ikatan PCB. Sifat getaran semulajadi telah diperolehi bagi keadaan terikat dan seterusnya pergerakan lenturan PCB akibat daripada kejutan. Keputusan simulasi menunjukkan bahawa bahagian tengah PCB mengalami lenturan yang paling ketara, di mana pendapatan ini adalah bersetuju dengan kajian-kajian baru yang berkaitan.

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GENERAL NOTATIONS

English Symbols

a	-	Length
b	-	Width
E	-	Young's modulus
f	-	Force
G	-	Shear modulus
$G(t)$	-	Acceleration at time t
G_m	-	Peak acceleration or maximum shock level
g	-	Gravitational acceleration
H	-	Drop height
h	-	Thickness
k	-	Spring constant
L	-	Length
M	-	Moment
m	-	Mass
M	-	Bending Moments
S	-	Compliance Components
T	-	Impact duration
t	-	Time
x	-	Displacement
$\dot{x}$	-	Velocity
$\ddot{x}$	-	Acceleration

Greek Symbols

υ	-	Poisson ratio
ρ	-	Density
ε	-	Strain
σ	-	Stress
λ	-	Wavelength
ω	-	Frequency
η	-	$= y/b$, dimensionless plate spatial coordinate
ξ	-	Damping ratio, or $= x/a$, dimensionless plate spatial coordinate

Abbreviations

CPU	-	Central Processing Unit
DOF	-	Degree of Freedom
FCBGA	-	Flip Chip Ball Grid Array
FE	-	Finite Element
FEM	-	Finite Element Method
FR	-	Flame Retardant
FRF	-	Frequency Response Function
FFT	-	Fast Fourier Transform
PBGA	-	Plastic Ball Grid Array
PCB	-	Printed Circuit Board
PCBA	-	Printed Circuit Board Assembly
SDOF	-	Single Degree of Freedom
SMT	-	Surface Mounting Technology

CHAPTER 1

INTRODUCTION

1.1 Introduction and Problem Definition

PCB is one of the major mechanical elements in most modern electronic systems. Transportation and handling of PCBs and PCB related products may generate shock and vibration on it. As a result, the PCB will experience deformation that creates excessive strain, which is eventually leaded to failure.

Although portable devices such as PDA or mobile phone are the products which were easily damage due to drop impact, this mechanical destruction is also the main damage factor for non-portable products such as motherboard package of desktop computer. Mishandling during transportation or customer usage may terribly damage the package.

In the microscopic of view, the PCB experiences deflection during drop impact. The PCB bending and mechanical shock will create extreme peeling stress **(Figure 1.1, 1.2)** that cracks the solder joints of electronic components that mounted on the PCB. Both Tee *et al*., (2004) and Yang *et al.*, (2000) had shown the results that the critical stress always occur at the outer row or corner solder balls. The disconnection of electronic circuit leads to malfunction of the product. Due to environmental protection concerns, the usage of lead-free solders instead of lead-containing solders had results more critical phenomenon because the higher moduli have more brittle mechanical responses (Yeh and Lai, 2000). Although, conventionally, board-level reliability usually refers to solder joint fatigue strength during the thermal cycling test (Tee *et al*., 2004) .

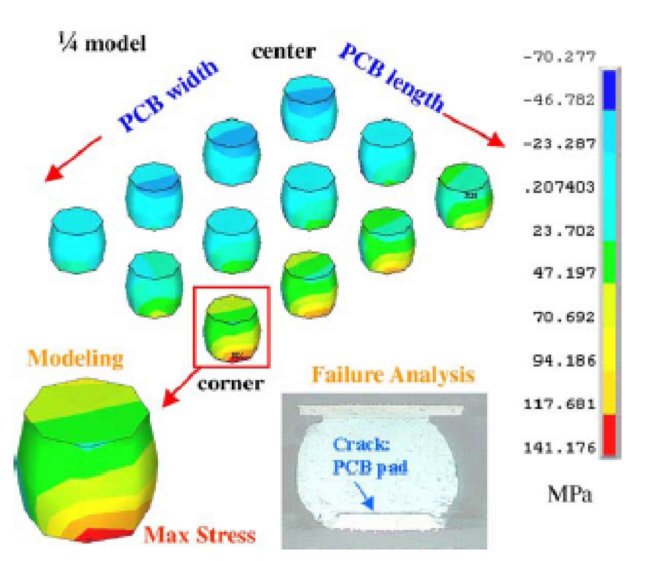

Figure 1.1 Critical solder ball and failure interface (Tee *et al*., (2004))

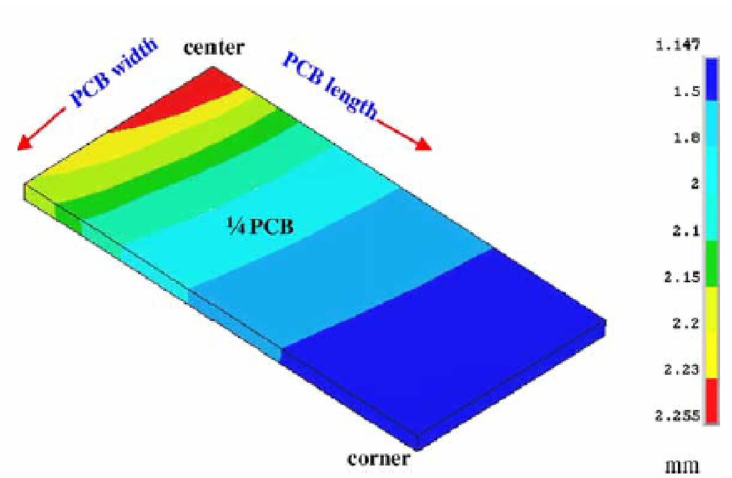

Figure 1.2 PCB warpage distributions during maximum bending (Tee *et al*., (2004))

Generally, PCB impact failure can be dividing into two fields: thermal impact and dynamic impact as **Figure 1.3.** The dynamic impact is part of structural dynamic field which concerns dynamic parameters such as deflection, velocity and acceleration of the whole structure. The study then can be furthered by stress, strain analysis under fracture mechanic analysis. Come to the last, the main reason of the study is to predict life of the product followed by product improvement which is the main concern for manufacturers in cost reduction and to benefit end users.

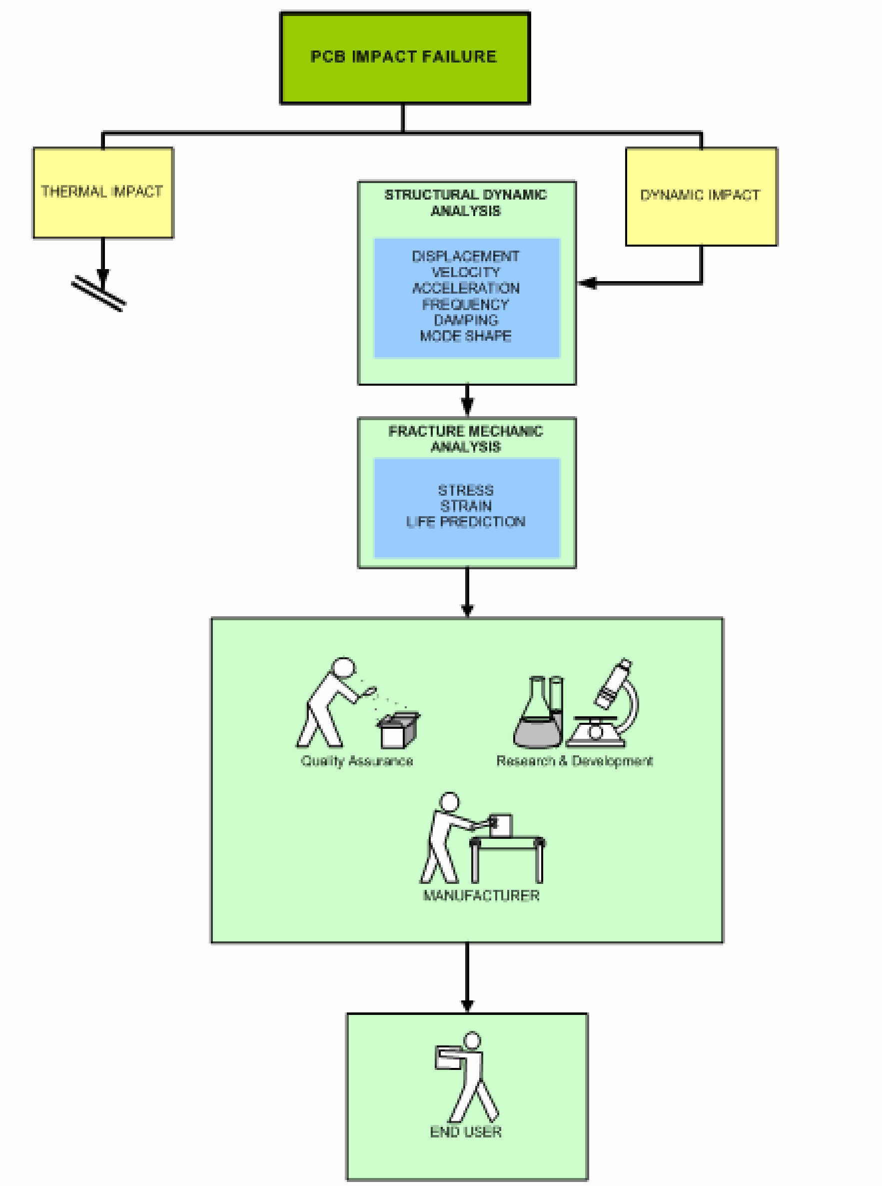

Figure 1.3 PCB impact failure and related further studies

1.2 Prior Research On Mechanical Vibration and Impact

It has always been a challenge to predict dynamic behavior of mechanical impact for PCB and related devices. Since 1980, with the blow up of PCB related products, the manufacturers are suffering from reliability of those products that may damage during handling and transportation. On the other hand, the end users are demanding for more robust products.

It was a difficult study to predict the final impact response on the product, even more difficult is to catch what actually happened inside the product during shock or drop that occur just within few milliseconds. In recent years, various impact predictions have been proposed to capture the dynamic behavior of the products.

Most researchers agree that board-level test is much easier to conduct and evaluate compare to the product-level test due to the complexity. Although there are numbers of studies have been done on board-level evaluation, only a few have done for product-level by simulation. However, it was a pre-requirement to study the board-level structural dynamic before furthering in product-level analysis if the result are frequency related data.

The investigations of vibration are presented as follows:

Wu *et al.,* (2002) had presents vibration analysis of PCB by FEA model and verified with the tested result. The simulation result had a close prediction to the tested data within 7% error range. Yang *et al.,* (2000) investigated dynamic properties of PBGA assemblies using experimental modal testing and FE analysis. Bare PCB and PCB assembly with PBGA modules mounted were tested and analyzed separately. The dynamic investigation was limited to free and force vibration. Geng *et al.,* (2003) evaluated solder joint shock reliability for Intel's desktop motherboard. Modal analysis was introduced to evaluate and calibrate the test board fundamental frequency. An external mass was mounted to the PCB to adjust the bare PCB behavior to the desktop system level. The FEM analysis validation had shown good agreement with the tested data. However, the shock testing and simulation were not included in this work. It provides only as a ground work for shock test evaluation. Chen and Lue, (2005) had study the free vibration characteristic of cross-ply laminated plates with a semi-analytical method. The result had been verified by comparing the present data with the exact elasticity solution for a simply supported plate. Allemang, (1983) had a detail discussion on the experimental modal analysis method, into four categories: forced normal mode excitation method, frequency response function method, damped complex exponential function method and mathematical input-output model method.

While the investigations of shock/impact are presented as follows:

Tee *et al*., (2004) predict impact life by studying PCB bending and mechanical shock. The drop test had been carried out and compare with explicit solver simulation. Detail study such as effect of component position, drop orientation and boundary condition of PCB had been evaluated. The quantitative approach provides both accurate relative and absolute impact life prediction. Wang *et al.*, (2004) carried out drop test FEM simulation, especially the methodology for analyzing the reliability of electronic devices under drop and impact. The structure with high complexity such as TV set packaging and Aluminum casing had been simulate with same method. Yeh and Lai, (2000) used the support excitation scheme in stead of the conventional drop test, in order to omit drop table modeling and contact methodologies. For experimental work, JEDEC drop test had been carried out. Both FEM and numerical studies had been done. The comparison for different drop orientation had been done in detail. Wang *et al.,* (2006) modeled and simulated the drop-impact analysis of PCB. The experimental study was carried out by actual drop test, where the images of specimen movements were capture with a high-speed camera. Detail study had been done using FEA simulation for four different models: isotropic, orthotropic, multi-layer uni-directional fiber and multi-layer fill-warp PCB models. Allen and Bogy, (1996) studied the effects of shock on hard disk drive by comparing drop test result from high speed camera with FEM modeling. The comparison of both method shown discrepancy due to the linear and non-linear conditions of simulation and testing, respectively. Ong *et al.,* (2003) had studied drop impact for both product-level and board-level of the Nokia Model 3210 mobile phone and its PCB. The mechanical responses were obtained by a load cell, accelerometers and strain gauges. The method was purely experimental, and several drop direction had been done to study the relationship between mechanical responds and drop direction. Suhir, (2002) had studied whether the shock tests could adequately replace drop tests. The analytical result shows that in order to mimic the actual drop test, the shock test loading should be as close as possible to an instantaneous impulse, and the duration of the shock load should be established base on the lowest (fundamental) natural frequency of vibrations.

1.3 Objectives Of The Project

The project is concerned with modeling of dynamic behavior of PCB subjected to mechanical shock loading. The objectives are as follows:

1) To understand current experimental method of mechanical shock tested on PCB (board-level) and PCB with chassis (product-level).

2) To simplify actual condition of product-level PCB and perform simulation modeling to obtain PCB dynamic responses due to free-fall and input-G.

1.4 Scopes of The Project

The scopes of project are as follows:

1) Undertake the FEM modeling of a PCB at simplified board-level condition.

2) Carry out further modeling study with isotropic and orthotropic model.

3) Conduct parametric study with the best model to investigate PCB response under effect of other features.

4) For verification, mechanical shock test of simplified product-level PCB should be performed either stimulating external impact on a static PCB or free-fall of PCB itself.

The remainder of the report is organized as follows. In Chapter 2, the theory of PCB structure, structural dynamic background, vibration test and conventional drop test is elaborated for better understanding of the solution method. In Chapter 3, the method of solution is introduced for vibration and shock/impact evaluation, for both experimental and FEM simulation method. Chapter 4 shows the results of PCB and chassis vibration analysis. Chapter 5 discussed the free-fall and input-G results for PCB with chips. In Chapter 6, conclusions of the research are presented with summary on major findings in the study. Future works for refining the research are recommended.