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# Modeling and Mode Shape Extraction of Ball Grid Array Package on Printed Circuit Board Soldered using Lead Free Solder Alloy – SAC405

**S Jayesh[1*] and Elias Jacob[2]**

[1] Department of Mechanical Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, Kerala, India-682022

[2] Department of Mechanical Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, Kerala, India-682022,Email – jayesh.jhe@gmail.com,

## ABSTRACT

Electronic apparatuses are wide-open to diverse vibration loadings. Vibration loading has become very substantial in the reliability valuation of contemporary electronic systems. The present challenge is to implement the vibration fatigue life examination quickly and precisely. Adding to that, lead is used as a solder joint in most of the electronics instruments. Lead is not eco-friendly due to its intrinsic nature of venomousness. A lead free solder joint is used in this paper which is 95.5Sn–4.0Ag–0.5Cu (SAC405).Vibration analysis is conducted on a printed circuit board element (PCB) on which plastic ball grid array package (PBGA) of specific design is mounted which is our test specimen. The package is soldered to the PCB using Lead free solder material. The PCB which is used in the analysis is divided by drawing lines into elements having discrete points and excitation is given at those points while noting down the response. The PCB and the package along with the solder joint are modeled and modal analysis is done to find the natural frequency. Modal analysis experiment has been done and the finite element analysis results were validated. The mode shapes are extracted at the natural frequencies using DIAMOND software. Frequency Response Function (FRF) real and imaginary parts are obtained through LabVIEW software. The FRF data which are gained through the experiment are given as input to the DIAMOND software. Geometry, nodes, tracelines were also given as input. Then the mode shapes were extracted using the software.

**KEYWORDS**: lead-free, solder, material, mode shape, natural frequency

## *Corresponding author

## Jayesh S

Department of Mechanical Engineering,

School of Engineering,

Cochin University of Science and Technology,

Kochi, Kerala, India-682022

Email – jayesh.jhe@gmail.com, Mob no: +919947291868

## INTRODUCTION

The ball grid array (BGA) package has become a foremost packaging type in previous years, because of its high capability for the input/output (I/O) counts. Connections mutually outside circuits for these packages are normally through either the solder nuts or pins under the package. This result would be reliability issues. Large number of solder ball and pin is present which is under high risk of failure. This problem has attracted around attention from researchers directed toward the BGA principle reliability in the soon years. Because of high quality of heat generated in such input-output circuits, many researches were based on the thermal stress induced and the reliability related issues. But when we consider the real world scenario, apart from these thermal stresses the components are subjected to dynamic loading. For example consider the vibration loading a component is exposed when it is transferred from one place to another. Real world applications related to automobiles, ships, aircrafts and electronic equipment, vibration caused stresses are the dominant ones and it cannot be neglected[1].

The lead which which was in wide usage for soldering is not eco-friendly due to its inherent toxicity. Electronic package industry is moving towards Pb-free solder in the past years because of emerging environment regulations[1]. This affected the reliability aspect of the solder joint as no other alternative alloy was able to replace the lead-tin solder alloy. This results in the failure of IC components in long run, which is a major impact on the electronics industry. From studies it was made clear that solder were the most susceptible area of failure under the influence of dynamic loading. Many of the electronic systems used in vibration atmosphere are exposed to random and harmonic excitations[2]. Therefore, quality assurance of the electronic systems generally uses random vibration as the test specification requirement for acceptance, screening and reliability qualification tests. First prototype is manufactured and after that the tests can be conducted. This is generally feasible only after taking a long time, and is frequently seen as inefficient and not add to economy as electronic technology markets nowadays are very fast developing. An electronic package is planned and designed so as to protect an Integrated Circuit (IC) from chemical, mechanical, electrical, and thermal harm. It should also provide interconnections to other devices. The integrated circuit is becoming more complex. According to the Moore's law: the transistor density of integrated circuit will double in every 18 months. Functioning is becoming more difficult as a result of this. As an example, Intel's 4004 chip had 2,250 transistors in 1971 while Intel Itanium 2 Processor had 410 million transistors in 2003[3].

However, a large slice of research on high cycle fatigue is only regarding with predicting the fatigue life of electronic components exposed to a sinusoidal vibration. Chen et al.[4] combined the vibration failure test, theoretical formulation for the calculation of the electronic component's fatigue life and FEA under sinusoidal vibration loading. Chen et al.[5] applied vibration fatigue test and analysis procedure for flip chip solder joint fatigue life examination. Perkins and Sitaraman[6] used linear sweep vibration analysis to illustrate the fatigue failure for ceramic column grid array (CCGA). Da Yu et al.[7] motivated on predicting the fatigue life of electronic components subjected to random vibration loading by adding both vibration tests and simulation analysis. Fang Liu et al.[8] for examining the solder joint reliability of BGA packages under random vibration loading, vibration reliability test of PCB assembly was done by using narrow-band random excitation. Yang et al.[9] implemented the out-of-plane sweep sinusoidal vibration test to assess the reliability of the plastic BGA (PBGA) assembly against vibration fatigue In the area of random vibration fatigue, Pitarresi et al.[10,11,12] considered the modeling techniques of circuit cards subjected to vibration loading. They investigated the response of surface mount lead/solder and predicted its fatigue life subjected to random excitation. Zhou et al.[13,14,15] matched the vibration reliability between the Sn-Pb and Pb-free solder joints under harmonic excitation and broad-band random vibration excitation. Some researchers were devoted to investigating the life prediction model under random vibration[16,17,18]. Robin Alastair Amy et al.[19] has done work to examine the accuracy of typical FE models used to predict the response of PCBs to harsh random vibration environment. It has been shown that if good data on the board properties exists, then even simple PCB FE models can deliver very accurate response prediction. Very less number of papers are there which deals with mode shape extraction of the BGA mounted on PCB using lead free solder joints.

## FINITE ELEMENT MODELING

A finite element model of the PCB with ball grid arrays is modeled using commercial software ANSYS 12.1. All components including the PCB was modeled by Solid element (SOLID45). All the nodes at the location of screw holes were fixed in all degrees of freedom because boundary conditions should represent those used in the vibration analysis. The image of the FEA model of the same is shown in the figure 1. Material properties used are given in the table 1

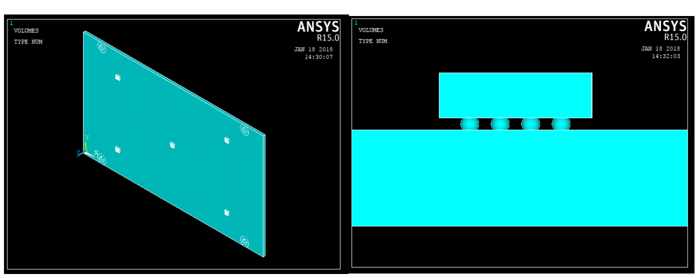


**Figure 1 a) Finite element model of the package b) Electronic package on PCB with solder ball**

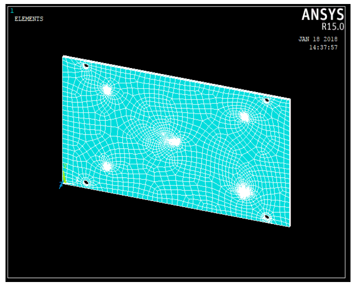


**Figure 1 c) meshing of the model**

**Table 1: Material properties**

| Sl no. | Materials | Young's modulus(Gpa) | Poisson's ratio | Density (Kg/m3) |
|---|---|---|---|---|
| 1 | PCB | 25 | 0.28 | 3400 |
| 2 | Solder ball(SAC405) | 53.3 | 0.28 | 7440 |
| 3 | Molding component | 20 | 0.3 | 1890 |

## EXPERIMENTAL SECTION

Two particularly designed BGA packages is mounted on the PCB. The BGA component, 19 x 19 mm, is mounted with 0.3 mm diameter lead-free solder balls with a pitch of 0.5 mm. The PCB is made of FR4 material with length of 132 mm and width of 76 mm. It has a thickness of 1 mm. Lead-free solder used for the experiment is 95.5Sn–4.0Ag–0.5Cu (SAC405) , the PCB assembly is mounted on the vibration shaker machine and screwed at all the four corners. Dynamic signal analyzer and accelerometer are used to note down the time history data of the shaker input as well as the PCB response.

## MODAL ANALYSIS

Two important parameters that describe the dynamic responses of test vehicle during vibration analysis are Natural frequencies and mode shape. Experiments was performed for modal analysis, also to determine the parameters, so that the FEA model can be validated. Figure 2 shows the analysis set-up which is made arranged for the modal analysis. The grids were marked on the board and the one of grid point is attached with accelerometer.All points were given excitation using an impact hammer with random input. The accelerometer and impact hammer used for the analysis are connected to a multi-channel DAQ assistant. The values are studied using LABVIEW software.

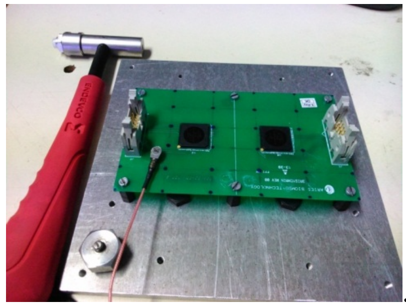

**Figure2 Test set up of modal analysis**

**Table 2: Comparison of FEA results and experimental results**

| Sl no. | Experimental Results(Hz) | FEA Results(Hz) |
|---|---|---|
| 1 | 161 | 151.76 |
| 2 | 310 | 300.25 |
| 3 | 411 | 423.37 |
| 4 | 579 | 585 |

## MODE SHAPE EXTRACTION

A mode shape expresses the deflection pattern associated with a certain modal frequency. The PCB is divided into elements having discrete points and excitation is given at those points while measuring the response. The response is measured at a point where the possibility for nodal point to occur is minimum. FRF real and imaginary parts are obtained through LabVIEW software. The FRF obtained by measuring the response at point i and an excitation at point j is equal to the FRF obtained by measuring the response at point j and an excitation at point i. Measuring the response for impacts at discrete points means that it captures the displacement at those discrete points so we can find a better picture of the deflection pattern at which it vibrates. Figure 3 shows the PCB divided into elements.

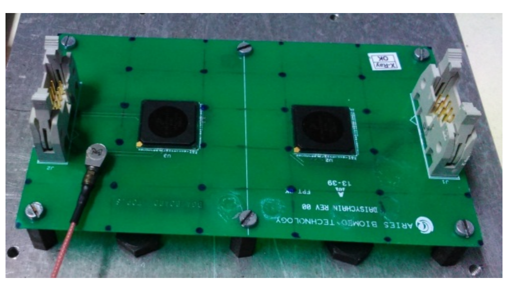

**Figure 3 PCB divided into elements**

The PCB is divided into elements having 36 points and the excitation is given individually at those points measuring the response with the accelerometer position fixed. FRF is computed for all the 36 points.

DIAMOND (Damage Identification and Modal analysis for Dummies) is a new suite of graphical-interface software algorithms to numerically simulate vibration analysis and to apply various modal analysis, damage identification, and finite element model refinement techniques to measured or simulated modal vibration data. DIAMOND has been developed at Los Alamos National Laboratory. DIAMOND is written in MATLAB, a numerical matrix math application which is available on all major computer platforms. DIAMOND is unique in three primary ways:

First is DIAMOND contains several of the most widely used modal curve-fitting algorithms. Thus the user may analyze the data using more than one technique and compare the results directly. This modal identification capability is coupled with a numerical test-simulation capability that allows the user to directly explore the effects of various test conditions on the identified modal parameters.
Second is the damage identification and finite element model refinement modules are graphically interactive, so the operation is intuitive and the results are displayed visually as well as numerically. This feature allows the user to easily interpret the results in terms of structural damage.

Third one is DIAMOND has statistical analysis capability built into all three major analysis modules: modal analysis, damage identification, and finite element model refinement. The statistical analysis capability allows the user to determine the magnitude of the uncertainties associated with the results[20].

No other software package for modal analysis or damage identification has this capability. The development of DIAMOND was motivated primarily by the lack of graphical implementation of modern damage identification and finite element model refinement algorithms. Also, the desire to have a variety of modal curve fitting techniques available and the capability to generate numerical data with which to compare the results of each technique was a motivating factor. The authors are unaware of any commercial software package that integrates all of these features. The FRF data which are obtained through the experiment are given as input to the DIAMOND software. Geometry, nodes, trace lines were also given as input. The geometry of the PCB defined is shown in the figure 4. The images of the mode shape extracted are shown in figures 5 to 9.

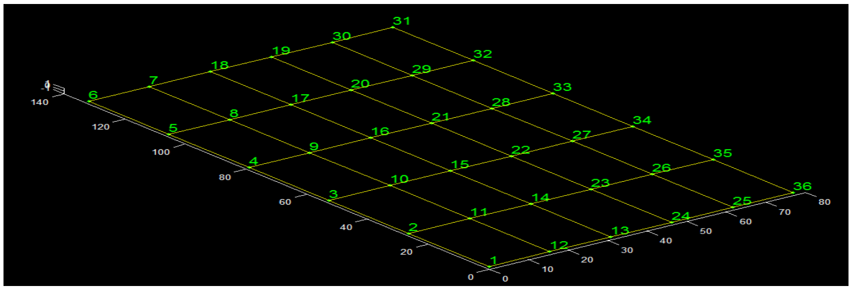

**Figure 4 The geometry of the PCB defined in DIAMOND software**

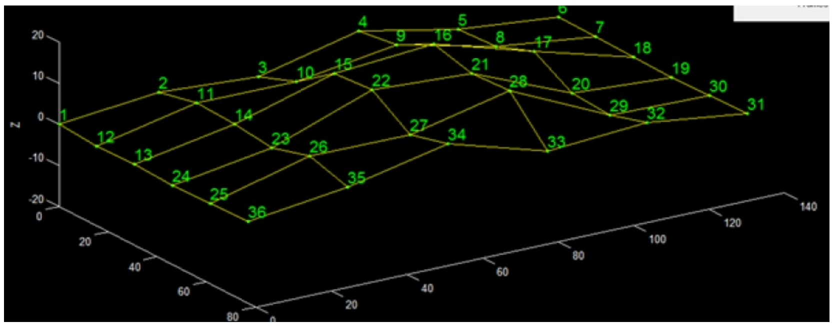

**Figure 5 First mode shape at 161 Hz**

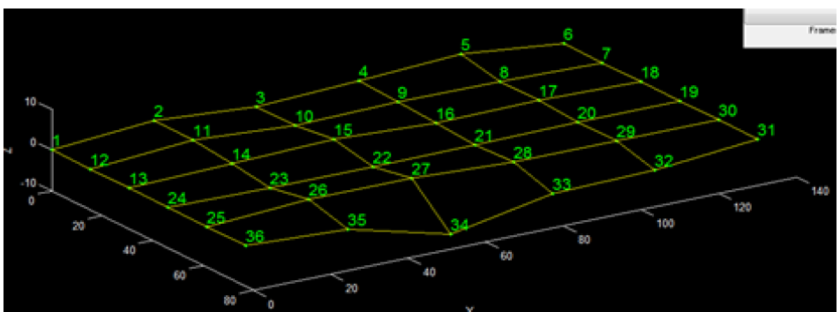

**Figure 6  Second mode shape at 306 Hz**

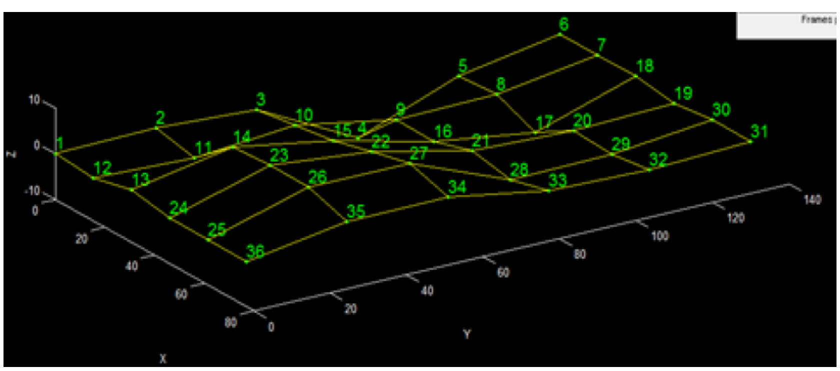

**Figure 7 Third mode shape at 411 Hz**

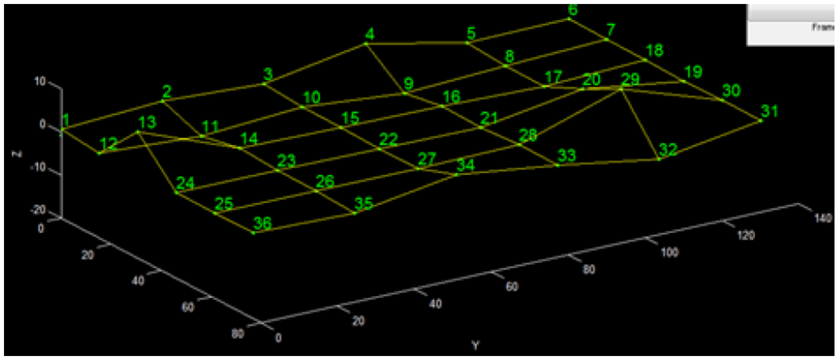

Figure 8 Fourth mode shape at 573 Hz

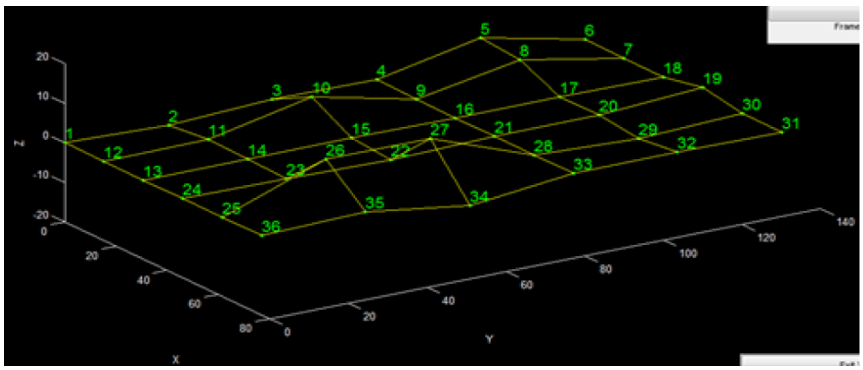

Figure 9 Fifth mode shape at 628 Hz

## CONCLUSION

The specially designed Ball Grid Array Package soldered on PCB is modeled in ANSYS software and the modal analysis was conducted to extract the natural frequencies. Experimental modal analysis was conducted and the results of the finite element based modal analysis were validated. The experimental results were matching with modal analysis done by the software. The mode shapes at these natural frequencies were extracted using DIAMOND software.

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