Numerical Simulation of Random Vibration Analysis for Ball Grid Array Package

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Abstract. This paper uses ANSYS Workbench (a finite element analysis software) to simulate BGA ceramic packing. The author models fixture, ceramic and metal steel. Then different thickness papers are laid on the BGA product. By random vibration analysis, the natural frequency and mode of the sample are obtained. According the results, the author discusses the relationship between different thickness papers and PSD-frequency curve. It provides a benefit instruction for the design of BGA packing.

Keywords: BGA, Finite Element Simulation, Random vibration analysis, ANASYS

1. Introduction
With the constant enhancement of the integration of BGA products, a large number of products have been in service for a long time under the working conditions where the vibration environment varies greatly [1]. During the service period, the operating environment of equipment is harsh, and it suffers from frequent vibration cycles and constant equipment startup and shutdown [2]. The solder ball in BGA package is easy to fall off during the service period. After the breakdown of products, it is necessary to collect products collectively for repair, which has a great impact on the project schedule and efficiency [3-4]. In the pages that follow, therefore, it will be argued that the relationship between different thickness of papers and frequency-PSD curve through random vibration analysis.

2. Theory of Random Vibration Analysis
The basic characteristics of the random signal x(t) in the frequency domain are described by the power spectral density function. It can characterize the distribution of vibration energy at different frequencies. When the integral of the autocorrelation function in the interval is finite, the autopower spectral density function is
\[ S(f) = \int_{-\infty}^{\infty} R_x(\tau) e^{-i2\pi f \tau} d\tau \] (1)

In the formula, \( f \) is frequency. \( S(f) \) and \( R_x(\tau) \) is a pair of Fourier transform. Their relationship is generally called the Wiener-Sinchin relationship, so there is

\[ R_x(\tau) = \int_{-\infty}^{\infty} S(f) e^{i2\pi f \tau} df \] (2)

Because \( R_x(\tau) \) is even function. In engineering, only the positive frequency part of the steady-state random process is calculated

\[ R_x(\tau) = \int_{-\infty}^{\infty} S(f) \cos(2\pi f \tau) df \] (3)

Therefore, the one-sided auto-power spectral density function is defined as \( G(f) \) to satisfy

\[
\begin{align*}
G(f) &= \begin{cases} 
2S(f) & f \geq 0 \\
0 & f < 0 
\end{cases} 
\end{align*}
\] (4)

Then there is

\[ R_x(\tau) = \int_{0}^{\infty} G(f) \cos(2\pi f \tau) df \] (5)

It can be seen from equation (5) that \( G(f) \) is the one-sided cross-power spectrum of \( f > 0 \), and \( G(f) \) is the acceleration auto-power spectral density function in the random vibration test of integrated circuits.

3. Finite Element Model

3.1. Establishment of the model

The initial model mainly consists of three parts, fixture (6061 aluminum alloy), ceramic panel (ceramic), and metal sheet (4J29 Kovar alloy). The simplified model of the sample and fixture is shown in the Figure 1.

Based on the initial geometric model, a simulation test is performed by laying a layer of paper (0.1mm thick) on the bottom of the ceramic panel, and laying different layers of paper on the metal sheet. The number of paper is as follows:

| BGA       | Thickness     | Bottom | Top    |
|-----------|---------------|--------|--------|
| 0.1mm+0.51mm | 1 layer       | 5 layers |
| 0.1mm+0.91mm | 1 layer       | 9 layers |
| 0.1mm+1.51mm | 1 layer       | 15 layers |
| 0.1mm+2.51mm | 1 layer       | 25 layers |

For multi-layer paper modeling, it is regarded as a whole modeling. The BGA sample profile is shown in the Figure 2:
3.2. Material properties
The material parameters of this analysis are as follows:

| Material          | Density (kg/m\(^3\)) | Elastic modulus(Mpa) | Poisson's ratio |
|-------------------|-----------------------|----------------------|-----------------|
| Paper             | 2700                  | 70000               | 0.33            |
| 6061 Al-alloy     | 700                   | 1000                | 0.3             |
| Ceramics          | 7500                  | 120000              | 0.24            |
| 4J29 Kovar alloy  | 8100                  | 210000              | 0.3             |

3.3. Meshing
Solid187 unit in Ansys to simulate various components. It is a high-order 3-dimensional 10-node solid structure element, which is used to ensure the calculation accuracy [5-6]. Meshing size: 3mm for fixtures, 0.5mm for other sizes (the meshing is obtained after a convergence test). The mesh is as shown Figure 3 and Figure 4:
3.4. Boundary condition
The model includes fixtures (bottom and cover), ceramics, metal sheets, and paper. Except for the bottom plate with fixed restraint (releasing the degree of freedom in the Z direction), other parts are in binding contact.

3.5. Input condition
This paper mainly focuses on random vibration analysis of BGA samples, and the known input conditions are as follows:

Table 3. Input power spectrum of random vibration analysis

| Frequency(Hz) | PSD(m/s²)²/Hz |
|---------------|---------------|
| 50            | 5.02          |
| 100           | 20            |
| 2000          | 5.02          |
| 1000          | 20            |

3.6. Analysis process
Random vibration analysis step:
1) Modeling of BGA sample
2) Obtain the modal solutions
3) Convert to spectral analysis
4) Define and apply PSD excitations
5) Solve
6) Analyze results

4. Random Vibration Analysis Result
Random vibration analysis is performed by changing the thickness of the paper, and then random vibration analysis is conducted. The frequency and PSD data of the observation point are shown as table 4 and table 5.

Table 4. Natural frequency data of different thickness of paper

| Order | Frequency (Hz) | 0.1mm+0.51mm | 0.1mm+0.91mm | 0.1mm+1.51mm | 0.1mm+2.51mm |
|-------|----------------|--------------|--------------|--------------|--------------|
| 1     | 8953.4         | 8969.3       | 8986.1       | 9034.5       |
| 2     | 10845          | 10855        | 10886        | 10950        |
| 3     | 13027          | 13027        | 13017        | 13000        |
| 4     | 18825          | 18752        | 18693        | 18369        |
| 5     | 20046          | 20016        | 19938        | 19904        |
| 6     | 23768          | 23792        | 23796        | 23817        |
| 7     | 26168          | 26159        | 26165        | 25692        |
| 8     | 27018          | 26971        | 26747        | 26025        |
| 9     | 31073          | 30057        | 28404        | 26042        |
| 10    | 32005          | 31081        | 30673        | 28596        |

By extracting the first two modes of each model, it can be known that the first mode is the external excitation direction (vibrating up and down in the Z direction), and the second mode is the torsional mode. The specific first two modes are shown as figure 5:
Figure 5. First two modes of BGA (0.1mm+0.51mm) sample

Table 5. Frequency and PSD data of different thickness of paper

| Frequency (Hz) | 0.1mm+0.51mm | 0.1mm+0.51mm | 0.1mm+0.51mm | 0.1mm+0.51mm |
|---------------|--------------|--------------|--------------|--------------|
| 50            | 482.8        | 482.8        | 482.8        | 482.8        |
| 100           | 1923.9       | 1923.9       | 1923.9       | 1923.9       |
| 152.63        | 1924.5       | 1924.5       | 1924.5       | 1924.5       |
| 255.26        | 1926.4       | 1926.4       | 1926.4       | 1926.4       |
| 357.89        | 1929.4       | 1929.4       | 1929.3       | 1929.3       |
| 460.53        | 1933.3       | 1933.3       | 1933.3       | 1933.3       |
| 563.16        | 1938.2       | 1938.2       | 1938.2       | 1938.2       |
| 665.79        | 1944.1       | 1944.1       | 1944.1       | 1944.1       |
| 768.42        | 1951.3       | 1951.1       | 1951         | 1951         |
| 871.05        | 1959.1       | 1959         | 1958.7       | 1958.7       |
| 973.68        | 1968.1       | 1968         | 1967.7       | 1967.7       |
| 1000          | 1970.6       | 1970.5       | 1970.2       | 1970.2       |
| 1076.3        | 1708.4       | 1708.3       | 1708         | 1708         |
| 1178.9        | 1433         | 1432.7       | 1432.6       | 1432.3       |
| 1281.6        | 1220.6       | 1220.5       | 1220.1       | 1220.1       |
| 1384.2        | 1053.8       | 1053.7       | 1053.4       | 1053.4       |
| 1486.8        | 920.41       | 920.33       | 919.97       | 919.97       |
| 1589.5        | 812.03       | 811.95       | 811.59       | 811.59       |
| 1692.1        | 722.73       | 722.73       | 722.36       | 722.36       |
| 1794.7        | 648.42       | 648.29       | 648.05       | 648.05       |
| 1897.4        | 585.91       | 585.91       | 585.52       | 585.52       |
| 2000          | 532.83       | 532.83       | 532.43       | 532.43       |
Finally, the displacement and stress distribution figure cloud diagram of random vibration analysis is shown in the Figure 7 and Figure 8.

**Figure 6.** BGA random vibration analysis

**Figure 7.** Random vibration analysis results of BGA sample (Displacement)
5. Conclusion
This paper uses ANSYS finite element software to perform random vibration analysis on BGA samples. The author models fixtures, samples, and metal sheets. By laying different thicknesses of paper on the bottom and top of the sample, the author discusses the influence of paper thickness on the frequency-PSD curve. The analysis results show that different layers of paper on the metal sheet hardly changes the frequency-PSD curve. Therefore, it is questionable to use this method to adjust dynamic response parameters.

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