Harmonic Response Analysis for Ball Grid Array Package Using Computer Finite Element Simulation

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Abstract. BGA package is selected as the research object in this paper. Workbench (finite elemental analysis tool in ANSYS) is used for harmonic response analysis. The author lays several paper sheets on the sample and builds the finite element model of clamp, ceramic and metal plate. Then, the model analysis is carried out. Based on this, it is converted to harmonic response analysis. According to the results, the author has found that there is no relation between the number of paper sheets and acceleration-frequency result. It promotes the development of electronic packaging reliability.

Keywords. Finite Element Analysis; BGA; ANASYS Workbench; Harmonic Response Analysis.

1. Introduction
BGA (Ball Grid Array) is a mainstream packing technology [1]. It has the characteristics of high integration, good thermal conductivity, small parasitic inductance and so on [2]. And it is widely used in PCB board interconnection and chip three-dimensional stack, which can significantly improve the interconnection of circuits. In the complex working environment, BGA package welding ball will be affected by vibration and impact, resulting in bending, fracture, virtual contact and other reliability problems [3]. Because BGA package is quite customizable, the application of them needs to consider many factors, such as the function realization, reliability, production cost and so on [4]. Therefore, it is necessary to study the reliability of BGA package, which provides instruction for BGA design.

2. Theory of Harmonic Response Analysis
Simple harmonic vibration is the simplest periodic vibration. The differential equation of forced vibration of a single free system under simple harmonic vibration can be expressed as

\[ m\ddot{x} + c\dot{x} + kx = -F\sin(\omega t) \]  (1)
In the formula, \( m, c, k \) represent the mass, damping and stiffness of the single degree of freedom system, \( F \) represents the force amplitude of the excitation, and \( \omega \) represents the circular frequency of the harmonic excitation. Let \( \omega_n^2 = k/m \), then get the standard form of the equation of motion

\[
\ddot{x} + 2\xi\omega_n\dot{x} + \omega_n^2 x = -\frac{F}{m} \sin(\omega t)
\]  

(2)

The formula (2) is a second-order non-homogeneous linear ordinary differential equation. The solution of \( x \) consists of two parts: the general solution of the homogeneous equation and the special solution of the non-homogeneous equation. When the system is under-damped, its general solution is transient response. The vibration frequency is a damped natural frequency, and the amplitude decays exponentially. Its special solution is steady-state response, and its characteristic is that it produces constant amplitude vibration under simple harmonic excitation.

Under simple harmonic vibration excitation, the system response is divided into two stages. The first stage is the transition stage, which is the stage where the above two vibration responses are superimposed. The amplitude of the transient response of the damped system decays continuously during the vibration process. The second stage is the steady state. After the transient response disappears, only the steady-state response stage remains.

3. Finite Element Model

3.1. Modeling

CAD models are built by Solidworks software, developed by Dassault, France, which contains three parts, fixtures, samples and metal plates as shown in the diagram.

![Fig. 1. BGA Harmonic analysis model](image)

After the geometric model is established, the finite element simulation test is carried out. Setting up different working conditions, that is, placing a sheet of paper 0.1 mm thick on a metal sheet. The number of paper is shown as TABLE1:

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

For the convenience of calculation, the model is considered as a whole when placing more than one piece of paper. The profile of the structure obtained by cutting the model is as follows:
3.2. Material
The material properties are set up in ANSYS, and the material parameters are obtained by consulting the literature and the designers of the components, as shown in Table 2.

Table 2. Material parameters

| Material         | Elastic modulus (Mpa) | Density (kg/m³) | Poisson's ratio |
|------------------|-----------------------|-----------------|-----------------|
| 6061 Al-alloy    | 1000                  | 700             | 0.3             |
| Ceramics         | 120000                | 7500            | 0.24            |
| Paper            | 70000                 | 2700            | 0.33            |
| 4J29 Kovar alloy | 210000                | 8100            | 0.3             |

3.3. Meshing
The convergence test is carried out before meshing. According to the test results, the grid size is 3 mm for the fixture, and the other is 0.5 mm. The unit property is set to solid185, which meets the calculation accuracy and enables the transient analysis to be carried out better, as shown in Fig. 3-4:

Fig. 2. Profile of BGA sample

Fig. 3. Mesh size
3.4. Boundary condition
According to the reality test conditions, the vibration direction is set to be perpendicular to the platform, while the fixture is fixed on the shaking table. Therefore, in the ANSYS, the constraint setting is to release the degree of freedom in the Z direction of the fixture, and other directions are set as fixed constraints.

3.5. Input condition
The frequency range is 20-2000Hz. When the frequency is 20-80.8242Hz, the double amplitude is 1.52mm, and the acceleration is 196m/s² (20g) at 80.8242Hz-2000Hz. Specific as shown in Fig. 5.

4. Harmonic Response Analysis Result
Harmonic response analysis was performed. Then, the author changed the thickness of the paper and applied the acceleration-frequency spectrum. The frequency and acceleration data of the observation point were calculated as shown in TABLE3 and TABLE4.
Table 3. Natural frequency of sample

| Order | 0.1mm+0.51mm | 0.1mm+0.91mm | 0.1mm+1.51mm | 0.1mm+2.51mm |
|-------|--------------|--------------|--------------|--------------|
| 1     | 8943.4       | 8972.3       | 8992.1       | 9044.5       |
| 2     | 10831        | 10840        | 10875        | 10961        |
| 3     | 13031        | 13034        | 13028        | 13011        |
| 4     | 18844        | 18749        | 18702        | 18374        |
| 5     | 20056        | 20022        | 19945        | 19911        |
| 6     | 23772        | 23785        | 23811        | 23825        |
| 7     | 26159        | 26169        | 26178        | 25702        |
| 8     | 27009        | 26968        | 26759        | 26031        |
| 9     | 31087        | 30062        | 28411        | 26056        |
| 10    | 32011        | 31076        | 30680        | 28609        |

After the natural frequency data are derived, the mode shapes of BGA modal analysis are viewed as shown in the Fig. 6. The first-order vibration mode of the fixture is the center moving in the Z-axis direction, and the second-order is the torsional mode.

(a) First

(b) Second

Fig. 6. Vibration modes of the first two order
Table 4. Acceleration and frequency data

| Frequency (Hz) | Acceleration (m/s²) |
|---------------|---------------------|
|               | 0.1mm+0.51mm | 0.1mm+0.91mm | 0.1mm+1.51mm | 0.1mm+2.51mm |
| 20            | 11.989        | 11.989        | 11.989        | 11.989        |
| 33.362        | 33.361        | 33.361        | 33.361        | 33.361        |
| 55.651        | 92.829        | 92.829        | 92.829        | 92.829        |
| 92.832        | 196           | 196           | 196           | 196           |
| 154.85        | 196           | 196           | 196           | 196           |
| 258.31        | 196           | 196           | 196           | 196           |
| 430.89        | 196           | 196           | 196           | 196           |
| 718.76        | 196           | 196           | 196           | 196           |
| 1199          | 196           | 196           | 196           | 196           |
| 2000          | 196           | 196           | 196           | 196           |

Fig. 7. Frequency-acceleration curve

Finally, the displacement nephogram and stress nephogram under harmonic response vibration are calculated. It is intuitive to see that the displacement is relatively small, and the stress changes greatly at the bolt constraint as shown in the Fig. 8 and Fig. 9.

(a) (0.1+0.51) mm

(b) (0.1+0.91) mm
Fig. 8. Distribution of displacement

(a) (0.1+0.51) mm

(b) (0.1+0.91) mm

(c) (0.1+1.51) mm

(d) (0.1+2.51) mm
5. Conclusion
In this paper, the BGA sample is simulated by finite element method. Modeling includes fixtures, samples, and pieces of metal. Modal analysis is performed first, based on the modal solution, and then harmonic response analysis is performed. The effect of paper of sheets thickness on frequency-acceleration parameters is discussed. The results indicate that the corresponding response curve can hardly be changed by setting different numbers of sheets on the metal sheet. To mediate dynamic response parameters using this method is not recommended.

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References
[1] Chen Xun, ZHAO Mei, MENG Guang. Analysis of dynamic characteristics of PBGA Solder Joint under impact environment [J]. Journal of Vibration and Shock, 2004(04):133-136+155.
[2] W. J. Greig. Integrated circuit packaging, assembly and interconnections: trends and options[M]. Springer, 2007.
[3] Y.J. Liu, T. Li, L.N. Sun. Design of a control system for a macro-micro dual-drive high acceleration high precision positioning stage for IC packaging [J]. Science in China Series E: Technological Sciences, 2009, 52(7):1858-1865.
[4] J.H. Zhao, V. Gupta, A. Lohia, et al. Reliability modeling of lead-free solder joints in wafer-level chip scale packages [J]. Journal of Electronic and Packaging, 2010, 132(1): 1-6.
[5] M. Spraul, et al. Thermal and Mechanical Simulation and Experiments in Microelectronics and Microsystems, 2004. EuroSimE 2004. Proceedings of the 5th International Conference on page(s): 437-442.
[6] Lee T , Lee J , Jung I . Finite element analysis for solder ball failures in chip scale package[J]. Microelectronics Reliability, 1998, 38(12):1941-1947.