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Reliability analysis of vibrating electronic assemblies using analytical solutions and response surface methodology

Mohammad A. Gharaibeh

Mechanical Engineering Department, The Hashemite University, Zarqa 13115, Jordan

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ABSTRACT

This paper introduces a reliability performance study of electronic assemblies subjected to harmonic vibration loading using analytical solutions and response surface methodology (RSM). The work involved a modification of a previously published analytical solution for the vibrating assembly problem. This solution is employed to calculate the fundamental resonant frequency of the system and the ball grid array (BGA) solder interconnect axial deflections. Using RSM, the geometric parameters of an electronic package, the size and thickness of the printed circuit board (PCB) and the component as well as the solder height and radius, effects on the assembly first natural frequency and the most-critical solder joint axial deflection is investigated and hence presented. The results showed that the natural frequency of the system as well as the critical solder deformations and thus reliability can be effectively affected by such geometric variables. The results of this study can be very useful for the design of electronic products in vibration loading environments.

1. Introduction

During shipping, handling and service life electronic devices are prone to vibration loadings which might result in solder joints failures. Studies showed that the main reason of such failure is due to bending difference between of the printed circuit board and the electrical component [1,2]. Numerous studies have been conducted to assess the reliability of electronic assemblies under mechanical vibration loadings using experimental techniques and finite element simulations [3–11].

In addition to experiments and finite element analysis (FEA), analytical methods were effectively used to characterize the packages dynamics and calculate solder stresses. Mindlin [12] used a two-degrees-of-freedom (2DOF) model in analyzing vibration properties of electronic products. Using the 2DOF approach, Aytekin et al. [13] computed the natural frequencies and vibration response of an electronic assembly. A ceramic column grid array (CCGA) package has been analytically modeled by a beam-spring-mass system [14]. The vibration-induced wire stress during the thermosonic wire bonding were analytically discussed by Wang et al. [15]. Recently, Gharaibeh et al. [16] presented an analytical solution which included Ritz method to derive the equation of motion of a vibrating electronic package. This solution was used to study the effect of PCB stiffness and solder geometries on the assembly high-cycle fatigue performance. One common problem that has been utilized in the reliability studies of electronic packages is the two elastically-coupled beams problem [17–22].

Response Surface Methodology (RSM) has been widely used in literature to examine and optimize the reliability behavior of electronic assemblies subjected to different type of loadings. Jagarkal et al. [23] employed RSM to improve and optimize the reliability performance of electronic packages subjected to thermal cycling. Fan et al. [24] utilized RSM to investigate the solder joint thermo-mechanical reliability in Wafer Level Packages (WLP's). Leong and his coworkers [25] considered RSM to optimize a standard flexible printed circuit boards (FPCB) in the flow environments in order to minimize the stresses induced due to fluid structure interactions. Also, RSM and genetic algorithms (GA's) were used to find the optimal geometries of rectangular and cylindrical fins attached to electronic packages to ensure maximum heat dissipation [26]. A state-of-the-art review on the multidisciplinary design and optimization methodologies used in electronic packaging can be found in [27].

This paper re-considers the analytical solution that is previously developed by the author [16] to evaluate the outermost solder interconnect axial deflections. Also, it employs the response surface methodology to investigate the geometric parameters of the PCB, component and BGA solder joints effects on the reliability performance of electronic assemblies under vibration.

This paper starts by introducing the assembly description and the FEA modeling details. The analytical solution derivation and verification processes are presented consequently. Finally, RSM was used to study the effect of the various geometric parameters of the system on the assembly first natural frequency and solder deformations and hence reliability performance.

E-mail address: mohammada_fa@hu.edu.jo.

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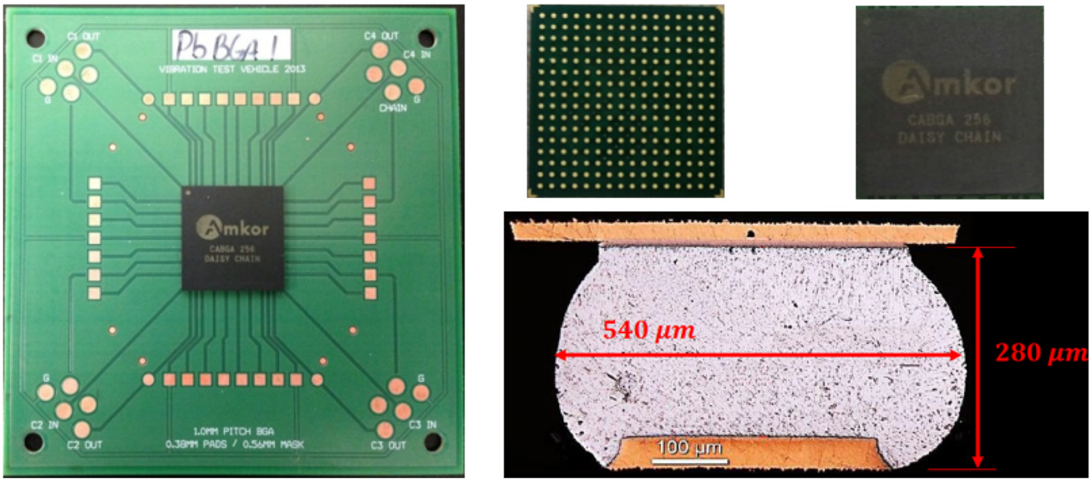

Fig. 1. Assembly description.

2. Assembly description and finite element modeling

As shown in Fig. 1, a squared printed circuit board of 76.2 mm length and 1 mm thickness, with a centrally-placed 17 × 17 × 1 mm^3Amkor CABGA 256 dummy component having 280 μm height and 540 μm width eutectic 63Sn37Pb BGA solder joints is considered in this paper. The solders are evenly separated by a 1 mm pitch.

ANSYS Release 17.0 [28] was used for constructing the FE model of the assembly. In this model, SOLID185 ANSYS element was used to generate the mesh. This model is depicted in Fig. 2.

The assembly material properties used in the FEA model are listed in Table 1. All the materials are assumed to be linear elastic isotropic. In order to simplify the analysis, the boundary conditions (BC's) imposed on the PCB are considered to be simple supports along all the four edges, i.e., the edges deflections as well the moments are equal to zero. These BC's were best simulated in the FE model by setting $u_x = u_z = 0$ on the top and bottom edges and $u_y = u_z = 0$ on the left and right edges of the PCB depicted in Fig. 2. It is important to mention that this FE model was fully validated previously in [16].

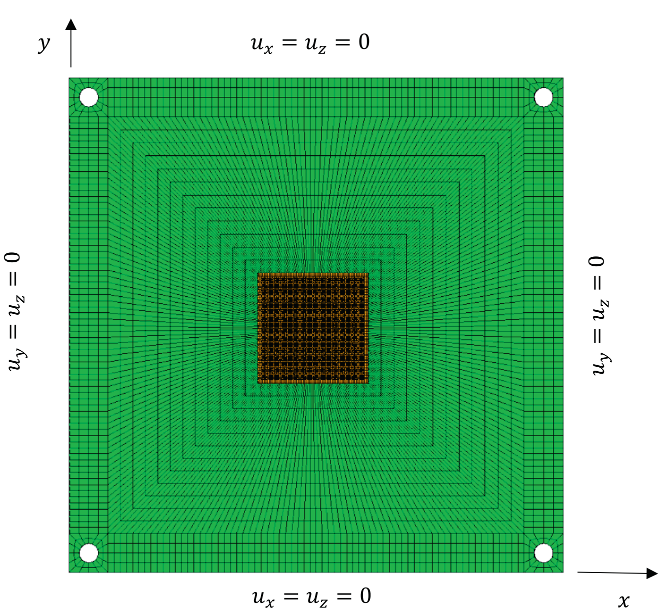

Fig. 2. Finite element model of the current assembly.

Table 1
Linear elastic material properties used in the FE model.

	PCB	Component	Solder joints 63Sn37Pb	Copper pads
Young's modulus (*GPa*)	32.0	27.0	34.0	120.0
Poisson's ratio	0.14	0.25	0.40	0.30
Density (kg/m^3)	3000	1100	8410	8800

3. Analytical solution details

Gharaibeh et al. [16] claimed that the electronic assembly can be faithfully described by a two elastically-coupled plates system, depicted Fig. 3, with the geometric and material parameters listed in Table 2. This analytical model suggested that the PCB is a bottom elastic plate; the component is a rigid top plate and both are connected by linear axial springs. Springs here, represent the solder interconnects. In that model and according to Ritz method, the PCB and component displacement solutions, $v(x,y,t)$ and $u(x,y,t)$, respectively, were written in series form of admissible functions composed of multiplication of the PCB mode shapes $V_i(x,y)$ or component mode shapes $U_i(x,y)$ by the time-dependent generalized coordinates $\eta_i(t)$ as

$$v(x,y,t) = \sum_i^N V_i(x,y)\eta_i(t)$$
$$u(x,y,t) = \sum_i^N U_i(x,y)\eta_i(t) \tag{1}$$

Gharaibeh's solution states that if this continuous system is subjected to base excitation, the vibration problem can be reduced to the simple single-degree-of-freedom (SDOF) system, shown in Fig. 4, with the governing equation:

$$M\ddot{\eta} + C\dot{\eta} + K\eta = C\dot{y} + Ky \tag{2}$$

where M, C and K are the mass, damping and stiffness coefficients, respectively, and expressed as:

$$M = \iint_{A_1} \rho_1 h_1 V_i V_j dxdy + \iint_{A_2} \rho_2 h_2 U_i U_j dxdy \tag{3}$$

$$C = \iint_{A_1} C_1 V_i V_j dxdy + \iint_{A_2} C_2 U_i U_j dxdy \tag{4}$$