Secondary Impact in Drop Testing and Damage Modeling of MEMS Microphone Assembly

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Background and Problem Statement

♦ Failure under dynamic mechanical stresses caused by impact and drop loading is a critical concern for reliability of portable, hand-held electronic products

♦ Modern portable electronic products utilize various MEMS devices:
  ➢ Sensors (acoustic, acceleration, angular velocity)
  ➢ Magnetometers
  ➢ Radio frequency devices

♦ In literature, relevant shock accelerations range from 15,000 G to 25,000 G based on [1 - 6]:
  ➢ Studies of usage conditions
  ➢ Internal collisions between the structures inside the product cover
  ➢ Achieved by Dual Mass Shock Amplifier (DMSA)

♦ Common failure modes are analyzed and modeled based on stress/strain histories from a calibrated multi-scale FEA model
Introduction: Drop Tower and DMSA

Secondary impact provides 40X amplification in peak acceleration [6]

Initial peak acceleration on DMSA base: 300 G
Secondary impact peak acceleration on DMSA Drop Table: 12,000 G
Drop Test Fixture & Specimen Architecture

- The board configuration is as per JEDEC standard JESD22-B111 [1]
- Drop acceleration is as high as 20000 Gs at fixture
- Secondary impact is further exploited in fixture design, by using finite clearance between the PWB and the fixture base [7]

**Diagrams:**
- **(a)** Zero clearance fixture
- **(b)** Infinite clearance fixture
- **(c)** Bottom plate clamp and spacers for finite clearance

**Notes:**
- a. zero clearance bottom plate clamp
- b. infinite clearance bottom plate clamp
- c. bottom plate and spacers for finite clearance
Test Vehicle and Results

- Audio response: measured after every 25 drops
- Averaged for: 67% components are failed
- Maximum number of drops is 500

<table>
<thead>
<tr>
<th>Failure Data (number of drops) (63.2% are failed)</th>
<th>Clearance (mm)</th>
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</thead>
<tbody>
<tr>
<td>Failure mode</td>
<td>0.2</td>
</tr>
<tr>
<td>Solder Fracture</td>
<td>2672</td>
</tr>
<tr>
<td>MEMS delaminated from microphone substrate</td>
<td>1258</td>
</tr>
<tr>
<td>Wire bond deformation &amp; fracture</td>
<td>948</td>
</tr>
<tr>
<td>MEMS structural damage</td>
<td>1299</td>
</tr>
</tbody>
</table>

Cross-section of microphone package
Level 1 PWB FEA Global Model

Calibration of PWB/Contact Properties

PWB Material Damping [8]
- Dynamic test: drop test with infinite clearance
- Dynamic FEA of free drop response

Contact Properties: Contact Stiffness and Damping
- drop test with secondary contact
- Dynamic FEA of impact: PWB to fixture

Rayleigh Damping: \( C = \alpha |\mathbf{M}| + \beta |\mathbf{K}| \)

FEA (mass proportional damping coefficient: \( \alpha = 150 \))

FEA (Contact stuffiness \( K=10 \), critical damping fraction (contact damping): \( \zeta = 1.5 \))
Global-Local Model ‘Handshake’ Boundary Conditions

- Displacement histories at footprint of component in Level 1 (global) model are transferred to corresponding nodes at mid-plane of PWB in Level 2 (local: MEMS microphone) model.
- Based on the Level 1 model output, the edge components (slide 4) always have the highest acceleration.
- In the current study, only the stresses/strains histories of edge components (upper bounds of accelerations) are used to build the damage model for the whole assembly.
Critical Failure Sites:

- Critical failure sites are addressed for:
  - die attach delamination
  - fracture of the component lid-seal
  - Critical failure site for wire-bond breakage failure is the first element of the wire (beam element)
Level 2 MEMS Local Model Stress Output: Effect of Component Orientation

Die Attach Stresses at Critical failure Sites [8]

- Von Mises' stress histories are not very sensitive to drop orientation
- Hydrostatic stress phase (wrt von Mises’ stress) is reversed
- Effect of component orientation needs to be included in the damage model

* Note: in principle, von Mises's stress is positive, this graph is only showing the phase relation between von Mises' stress and hydrostatic stress
Damage Models

Model A: Die attach fracture

\[ D = \frac{k}{\sigma_H(t) + \sigmavm(t)} \]

\[ \sigma_{\downarrow} H \uparrow_0 = 35 \text{MPa}, \quad \Delta \sigma_{\downarrow} vm \uparrow_0 = 24.16 \text{MPa} \]

\[ k = 19.02, \quad n = 2.54 \]

Model B: Solder fracture

\[ D = \frac{k}{\sigma_H(t) + \sigmavm(t)} \]

\[ \sigma_{\downarrow} H \uparrow_0 = 35 \text{MPa}, \quad \Delta \epsilon_{\downarrow} vm \uparrow_0 = 1.58 \times 10^{-3} \]

\[ k = 4.97, \quad n = 2.88 \]

Model C: Wire bonds fracture

\[ D = \frac{k}{\Delta \epsilon_{\text{bending}}} \]

\[ \Delta \epsilon_{\downarrow 0} = 3.55 \times 10^{-2}, \quad k = 1.05 \times 10^{-3}, \quad n = 0.95 \]

\[ \sigma_{\downarrow} H \uparrow_0, \Delta \epsilon_{\downarrow} vm \uparrow_0, \Delta \epsilon_{\downarrow 0}, \Delta \epsilon_{\downarrow} vm \uparrow_0 \text{ are reference values selected from 0.2 mm clearance, component downwards} \]

Early termination of the test, no failure was observed

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Damage Model: Summary

Model: predicted life (when 63.2 % failed) (3 modeled failure modes)

Experiment: drop test (when 66.7% components are failed)
Damage Model: Conclusions

• According to the damage models, components facing upward in the drop test are about twice more durable than component facing downwards, which agrees with drop test result for the whole component
• The damage model of the dominant failure mode at 0.2 mm clearance (wire bond fracture) is not presenting the expected sensitivity to orientation
• MEMS failure mode is not modeled, which may result in earlier failure than wire bond fracture at 0.2 mm clearance
• Orientation sensitivity at 0.2 mm clearance may be improved by modeling MEMS failure modes
Conclusions

- Secondary impacts (caused by finite clearances between the PWB and the fixture) amplify the drop severity, as indicated by the drop durability of the MEMS microphone packages. It has been proved by the results of the physics based damage models in this study.

- Wire bond fracture, solder fracture, MEMS detachment from microphone substrate and MEMS structural damage, are found to be the most common failure modes in this study. Physics based damage models for the first three failure modes are developed.

- Durability of the MEMS microphone is sensitive to drop orientations. Two times of difference between durability of the components facing up vs. components facing down is confirmed by the damage models.

- The dominant failure mode of the MEMS microphone packages is found to vary as clearance between PWB and fixture base changes. It agrees with the damage modeling results, but the failures can be eliminated by proper packaging design.
REFERENCES

3. ETSI Standard ETSI EN 300 019-2-7, Environmental Engineering (EE); Environmental Conditions and Environmental Tests for Telecommunications Equipment; Part 2-7: Specification of Environmental Tests; Portable and Non-Stationary Use.