Open Source Random Vibration Testing of Off the Shelf Data Center Hardware

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The Era of AI introduced significant complexity and miniaturization to the mechanical structure of Data Center Hardware. Electronic components inside DC hardware such as servers and switches are smaller, denser, and more complicated structurally. As cloud services and AI become more integral to daily lives, shock and vibration induced intermittent or permanent failures in production can lead to real world consequences, affecting people's day to day lives.

Moreover, AI is reaching technologies such as edge computing, autonomous vehicles, and robotics. The hardware developed for data centers today could very well be used to power these technologies in the future, making shock and vibration testing even more critical to their reliability and long term performance.

This paper highlights the methodology Google developed to tackle these challenges, and capabilities that makes random vibration testing more useful and meaningful to the broader ecosystem, such as:

1. **Field Data Measurement, Analysis, and Replication in Lab Environments**
2. **Advanced Modal, Strain, and Motion Analysis of Common Data Center Hardware**
3. **High Speed Microscopic Motion Analysis of Components**
4. **Fatigue Analysis for Transportation and Supply Chain Environments**

These methodology and capabilities will be shared in the project titled "Open Source Random Vibration Test of Off the Shelf Data Center Hardware". The hope is that an open platform will encourage future engagement and collaboration, and make random vibration testing useful and accessible across the ecosystem and beyond. This project was formally announced at the 2024 OCP Global Summit on Oct. 17th, 2024.

I. Introduction

Historically, mechanical testing existed in the state of "Technology Island". Each company develops and implements their own test methods that are kept confidential, and makes it very hard to promote collaboration, retain knowledge, and scale the work across the whole ecosystem. "Tech Islands" is ultimately unsustainable in the long term, and leads to a tremendous amount of redundant work. These efforts also very rarely lead to industry wide impact, forcing companies to re-invent the wheel each time.

An open platform will alleviate some of these challenges by putting forth a body of past experience, knowledge, test data, and test setups easily accessible to the public that can serve as the foundation for future work.

II. Random Vibration Testing Methodology, High Level Over View

Random vibration testing, in the context of data center hardware, evaluates whether the components, subsystem, machines, and fully integrated rack systems common in Data Center Hardware will withstand vibration induced mechanical stress throughout the data center supply chain.

The follow types of vibration are common in the data center supply chain:

- Truck vibration from local and long range shipment
- Plane vibration from world wide shipment
- Handling with forklift and pallet jacks at warehouse and loading dock environment
- Pushing of racks from loading dock to dc floor
- Handling by hand at bench top (assembly, repairs, troubleshooting, etc)

In the race to build data centers around the world, "L11 Manufacturing", the idea that fully populated racks are assembled, brought up, tested, transported, and installed in a data center as an integrated solution, is key to deployment velocity. L11 Manufacturing significantly speeds up the supply chain, but creates a lot of challenges for mechanical testing. The movement of masses and materials inside a fully populated rack leads to compression and tension at the machine, PCBA, component, down to the molecular level, and this storing and releasing of strain energy leads to fracture, and ultimately intermittent and permanent failure in the data center.

One of the most important lessons from decades of component level shock testing is the idea that damage can occur at the components, but the unit under test could still pass functional tests afterward. Any fracture developed during high levels of stress and strain during testing has returned to neutral position afterward, allowing the material to be in contact again, as illustrated in Fig 1.

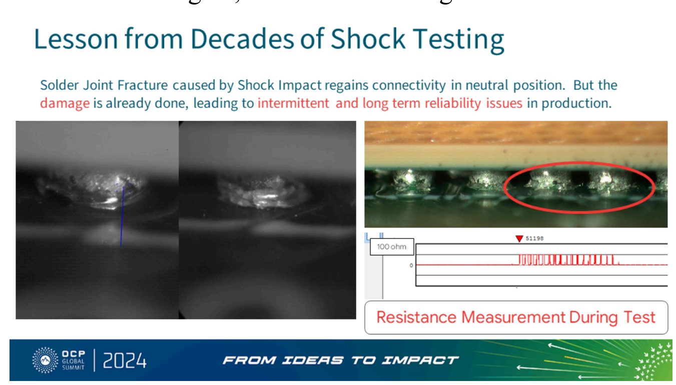

Figure 1. *Evidence of facture under BGA Solder Joint during testing*

What’s important about random vibration is that these kinds of damages accumulate over long periods of time. The lower the amplitude, the longer it takes. At the end of the day, it’s still very much a classical story of Stress vs. Strength. So both sides need to be explained clearly. This can be expressed in terms of factor of safety, where any value above one means there is margin, and anything below doesn't.

One of the long term goals of this project is to have such results available for a wide range of electronics components common in data center hardware, so that the risk of mechanical damage of any particular system can easily be evaluated.

III. Random Vibration Testing Methodology, Capabilities

A. Field Data Measurement and Analysis

To understand random vibration in the real world, Google undertook large scale field measurements throughout its DC hardware supply chains. A large number of portable vibration data acquisition units with capacity for 10 hours of continuous recording at 3000 samples per second were used in field experiments spanning between 2017 and 2023, as illustrated in Fig 2., and more than 2.0 x 10^9 data points were captured to help further the understanding of vibration conditions in the global supply chain.

Having comprehensive field measurements allow users to assess how to properly test product prototypes in lab environments. While the field recordings can be played directly on a shaker table, that could mean testing for days, if not longer. Such test duration is often not feasible. Google had to learn how to break the measurements down to fundamental properties such as amplitude, frequency range, and cycle count to create custom shaker table profiles for specific products.

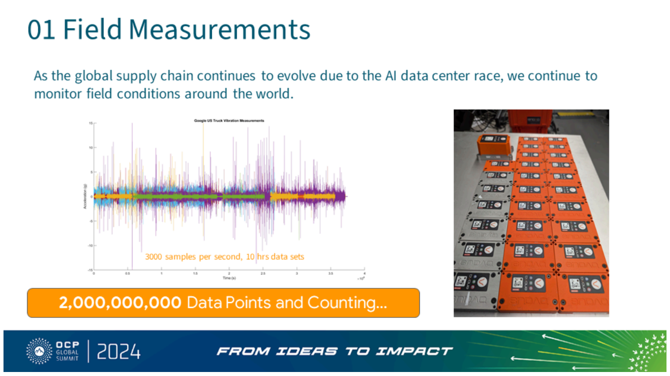

Figure 2. *Portable vibration data acquisition unit for field measurements*

B. Advanced Modal, Strain, and Motion Analysis of PCBA

To understand the location, magnitude, and direction of mechanical stress inside the DC hardware during random vibration, as well as the behaviors of the PCBA and critical components inside, the following techniques are implemented during testing:

- High Speed Camera, in combination with Motion Amplification were used to study the general movement of PCBA and components during testing. A tremendous amount of movement can be observed at heatsinks, memories, fan modules, as well as their movement relative to each other.
- Extensive strain measurements were performed around critical components such ASIC and Interconnects. In one example, 20 rosette strain gauges were placed to study behaviors of key components. In another example, 32 rosette strain gauges were placed to understand the curvature surrounding a single ASIC and Heatsink (Fig 3).
- Displacement measurements were also performed, which provides additional information such as the movement of large numbers of heatsinks in one machine and the exact displacement of an ASIC and surrounding area of PCB in another (Fig 4).

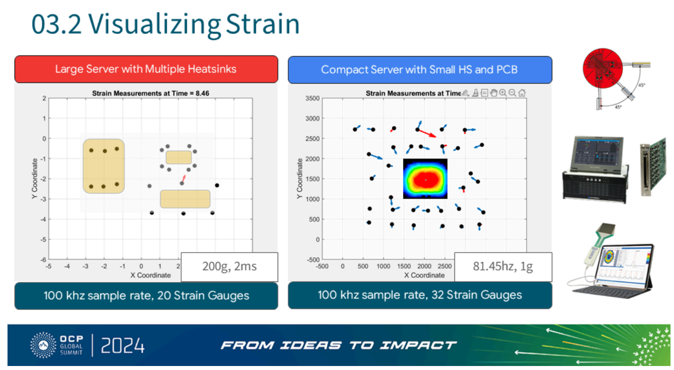

Figure 3. *Extensive strain measurements during vibration testing*

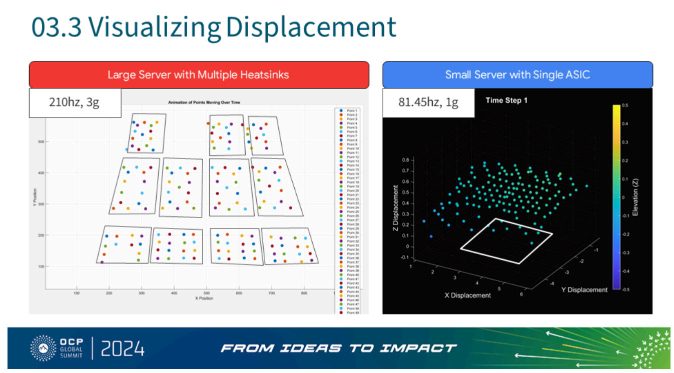

Figure 4. *Displacement Measurement during vibration testing.*

C. High Speed Microscopic Motion Analysis of Components

High-Magnification Zoom Lens, in combination with high speed camera and motion tracking capabilities, allow users to observe the motion of surface-mount electronic components on the PCB. Motion tracking allows users to perform displacement measurements of these components and study their dynamic behavior quantitatively (Fig 5).

At that level, mechanical damages can be observed over time - at least, ones visible to the eye on the surface. This level of visualization, in combination with traditional failure analysis techniques (cross sectioning, dye and pry, x-ray), helps users achieve a better level of understanding than traditional measurement techniques.

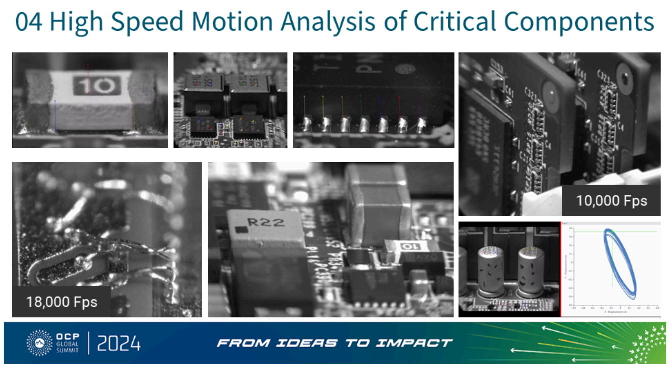

Figure 5. *Motion Analysis and Tracking during vibration testing*

D. Fatigue Analysis for Transportation Vibration

The original vibration condition recordings and advanced modal, strain, and motion analysis techniques enable fatigue analysis and calculation of factors of safety for specific components, in specific machine/rack configuration, and specific vibration conditions. An example was described during the presentation of this project to illustrate how such results were calculated in a step by step fashion. Final results also show how factor of safety varies depending on the specific route of the supply chain (Fig 6).

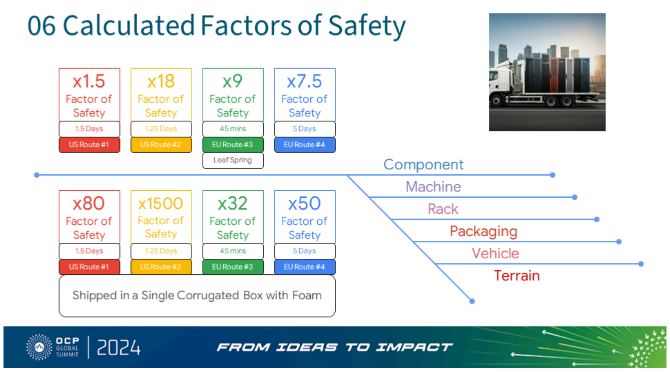

Figure 6. *Factors of Safety Calculation after testing completed.*

Again, such calculations allow users to evaluate the risk of damages of specific designs, and help companies, suppliers, and customers prioritize resources on ones most likely to lead to issues in production. The various analysis performed also provides insights into the underlying dynamic behavior of the components, materials, and geometries, and helps create more durable designs in the future.

IV. Conclusion

Taking a step back toward the idea of "Tech Island" - many of the techniques described above had to be reinvented or rediscovered as the methodology for random vibration testing had to be put together from the very beginning. That's because historically, many of these techniques were kept confidential within the companies who had the resources to develop them. While a lot of these past experiences and knowledge was published as technical papers and industry standards, most notably Intel's "Intel Strain Measurement Methodology for Circuit Board Assembly" and IPC/JEDEC-9703's "Mechanical Shock Test Guideline for Solder Joint Reliability", they are only the surface of a very large body of work that are now stored away in databases inside the companies. It takes a tremendous amount of time and resources to re-develop such methodology, and that is not feasible for many companies or organizations. "Tech Island" is ultimately unsustainable in the long term.

In the current Era of AI, where products are based on critical components such as chips, memory, and interconnects, many companies find themselves needing to build their own product around them. They have to perform their own testing during the development cycle, but at the end of the day, the tests are done on basically the same critical components. "Tech Island" leads to a tremendous amount of redundant work, and most important of all, this work rarely leads to industry wide impacts. There isn't a commonly agreed upon way to package the critical components in materials, geometry, and form factors that ensure the long term reliability of systems built around these components. There isn't even a commonly accepted suite of tests that the components, machines, and fully integrated racks must be subjected to. And there isn't even a widely agreed upon set of requirements that such products must satisfy.

While a lot of these issues require deep ecosystem wide engagement and collaboration to solve, Google is committed to doing its part to push the work forward. The "Open Source Random Vibration Test of Off the Shelf Data Center Hardware using Off the Shelf Methods and Solutions" project was formally announced at the 2024 OCP Global Summit on Oct. 17th, 2024, with the hope that an open platform will promote future engagement and collaboration and make random vibration testing useful and accessible across the ecosystem and beyond (Fig 7).

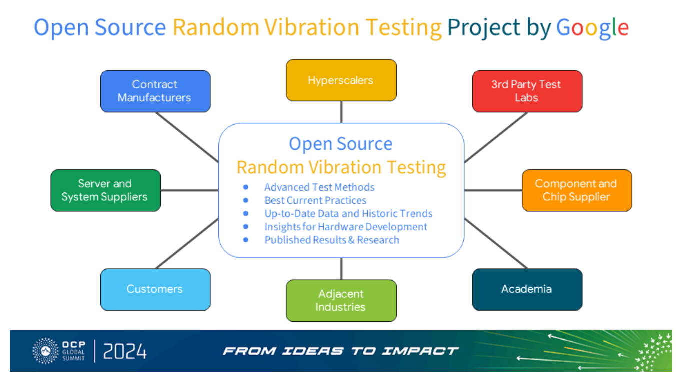

Figure 7. *Open Source Random Vibration Testing of DC Hardware.*