GOOGLE'S RANDOM VIBRATION TESTING METHODOLOGY, OPEN TEST DATA

Part 3.1: 3D DISPLACEMENT DATA OF A MACHINE DURING RACK LEVEL VIBRATION TESTING
REVISION A

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ASTM d4169-14 Truck Profile, Assurance Level 2, Rack Level, 4000 Frames Per Second
Video link: https://youtu.be/0C2t9vNmBXU

The best part about 3D data is its ability to communicate stress distribution and concentration with simple pictures. Very little training or experience is needed to look at high speed videos with 3D data to understand whether modes identified during sine vibration are re-occuring during random vibration.

Lenovo SR650 V2 3D Displacement During Rack Level Test, Truck Transportation

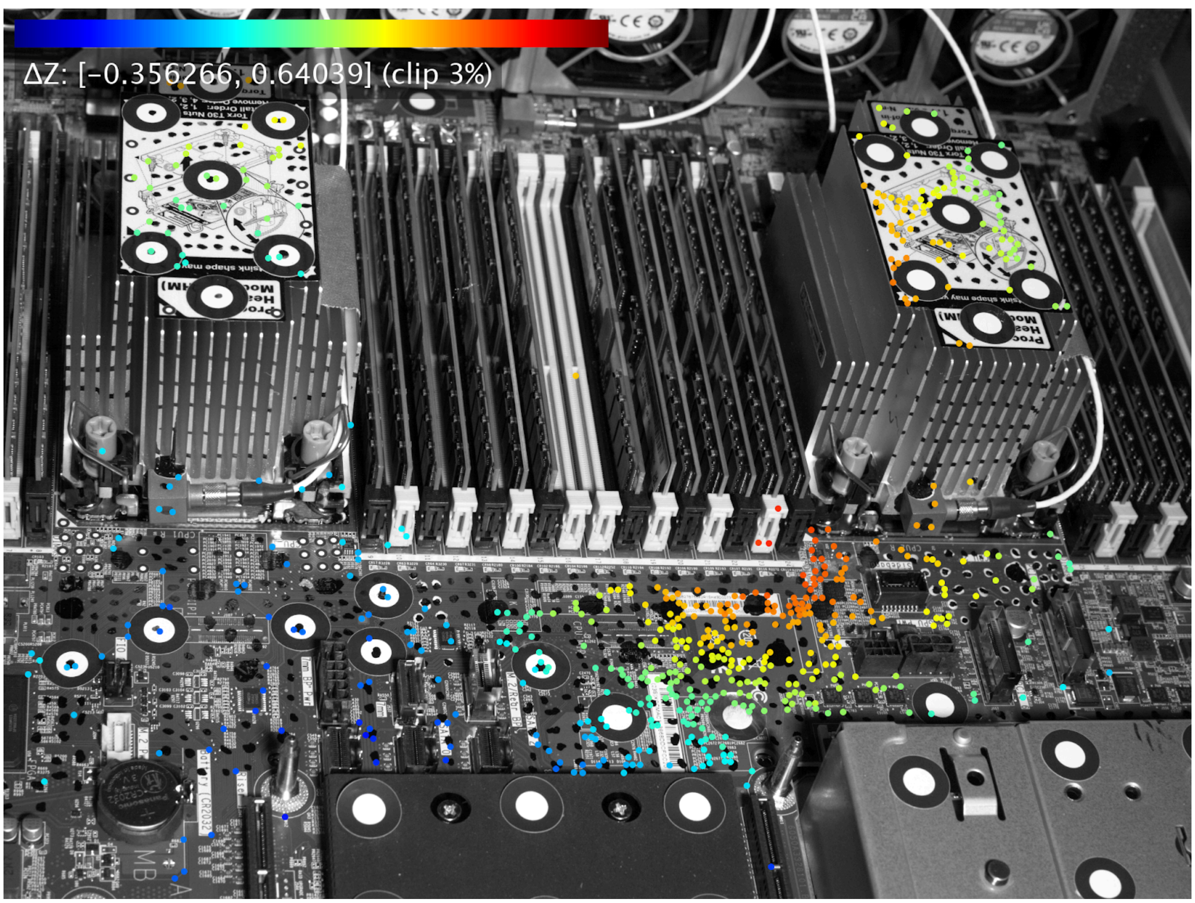

Figure 14.

There is something special about 3D displacement data of random vibration that has to be seen in video format. The modes from sine vibration are definitely re-occurring, but a lot of other things are going on as well:

- High frequency jitter of the heatsinks during the slow frequency modes
- Various modes mixing and interacting with each other
- The slowness of the PCB movement, which looks more like breathing than anything else
- All the components' movement, whether 3D data is available or not

Lenovo SR650 V2 3D Displacement During Rack Level Test, Truck Transportation, Frame 25 Thru 376

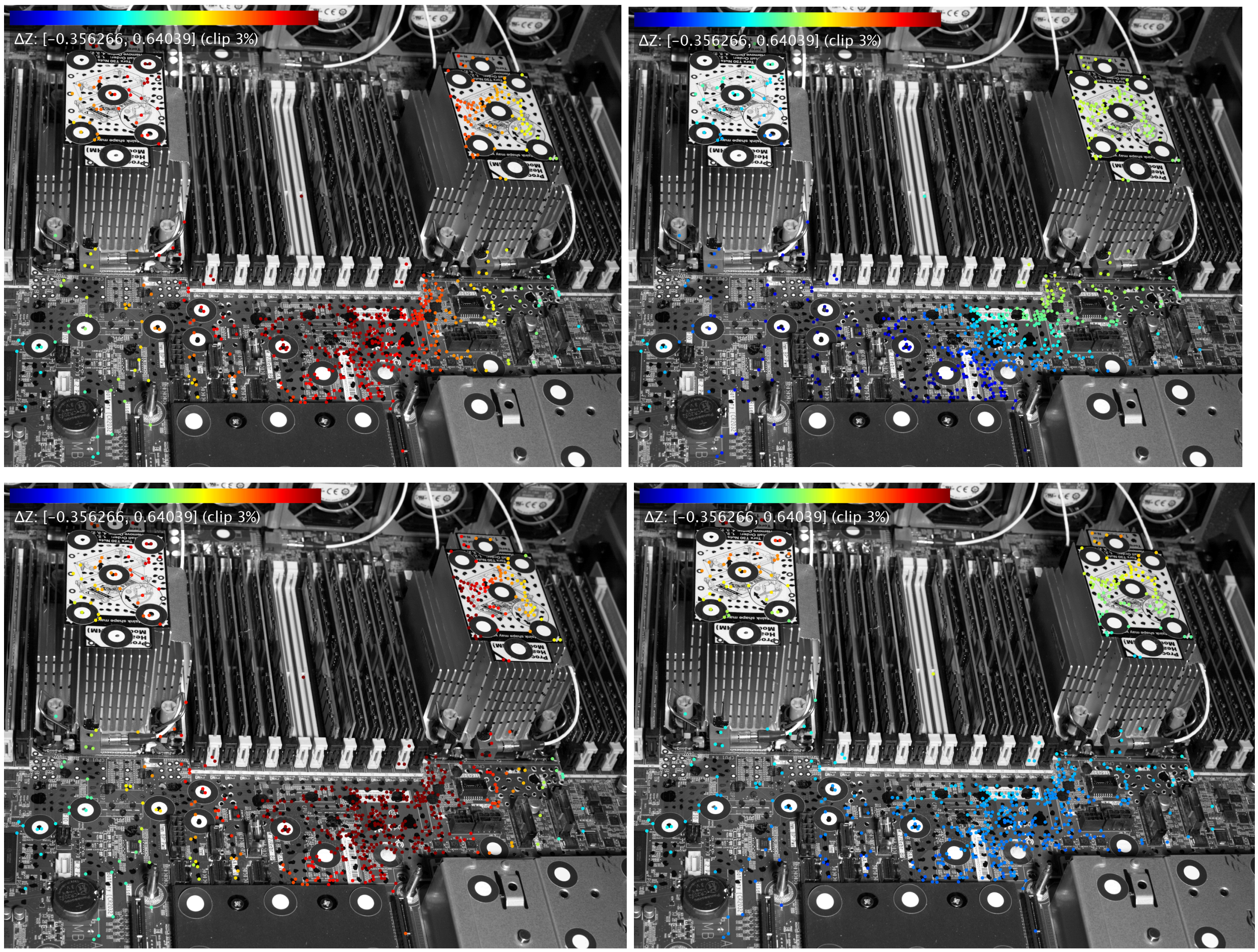

Figure 15.

Random vibration really isn't something that can be described with simple acceleration and strain plots.

Tracking 3D Displacement For Prolonged Periods of time

Random vibration poses a difficult challenge for 3D displacement measurement in terms of the amount of data to analyze and how much can be reasonably be achieved using typical lab desktop or laptop computers.

Normally, during sine vibration, only a few cycles of the vibration are needed to visualize the mode shape. At 24Hz, only 1/24 Hz = 0.0416 seconds are needed to observe the motion of 1 cycle. At 4000 frames per second, that's (1/24 second per cycle) / (1/4000 second per frame) = 166.66 frames to show a full cycle. **I typically analyze 200 to 500 frames to ensure the motion is repeatable**.

There is no such certainty with random vibration. How often a specific frequency is repeated depends on how the shaker table controller operates and what parameters are used. Modes may be overlapping with each other, interfering constructively or destructively with each other. That's why we want to capture as much data as possible. When we do that, we hit real limits in terms of:

1. Storage capacity at high speed cameras (up to 256GB RAM and up to 1TB for on-camera storage).
2. Computation capacity of typical laptops and desktops, which limit how many points can be analyzed using algorithms/models such as digital image correlation, segmentation-anything, and stereo matching in parallel.
3. Amount of time available for data analysis.

With a single server with 128GB RAM on Google Cloud, 800 points for sine vibration can be analyzed over 500 frames in 8 to 12 hours. When the **number of frames increases to 64,000 (16 seconds)**, near the maximum RAM capacity of the v2640 cameras at 2048x1952 resolution and 4000 frames per second, that amount of time **increases to 1,024 to 1,536 hours, which is 43 to 64 days(!)**.

One way around that to **reduce the number of tracked points**. After major modes were identified during sine vibration, 8 points were chosen to show 1) which mode was excited, and 2) at what amplitude. Even then, it still took several days and some trial and error for the pieces to come together:

1. 8 key points at the edge of PCB and top of heatsinks were chosen so that a) rigid body motion can be removed, and b) relative displacement can be calculated to demonstrate mode shape and amplitude.
2. These points were tracked though the 64,000 frames high speed videos using open source digital image correlation algorithms.
3. The points were calibrated and triangulated to calculate real world 3D coordinates.
4. Rigid body motion was removed to achieve 3D relative displacement data.
5. Points at the top of the heatsink were plotted and analyzed to calculate the amplitude and number of cycles of relative displacement.

Example Lenovo SR650 V2 2D Displacement Tracking During Rack Level Test, Left Camera, 20,000 Frames

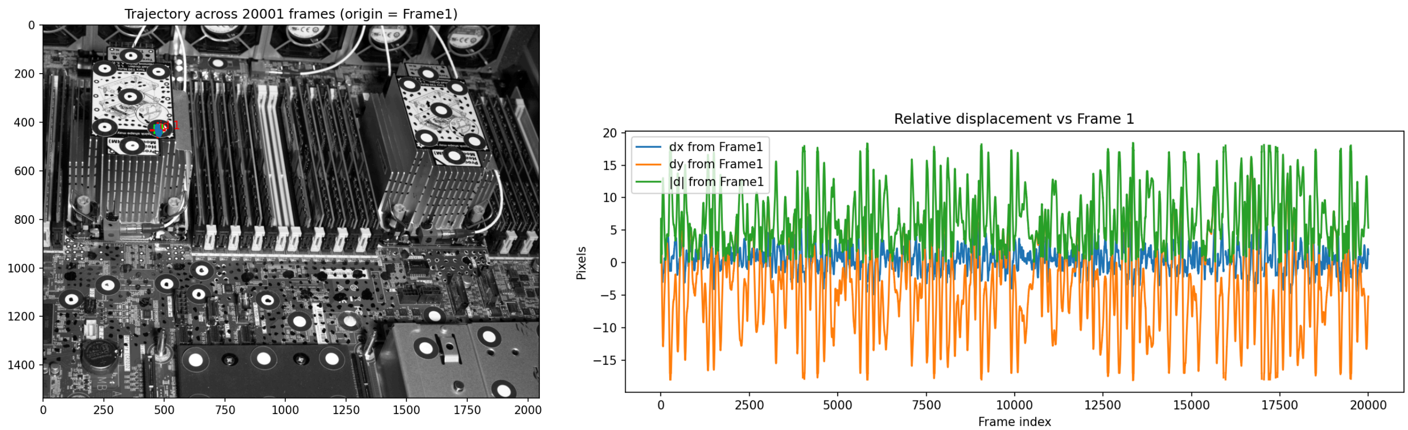

Figure 14.

Example Lenovo SR650 V2 Z Relative Displacement During Rack Level Test, Top of Heatsink, 20,000 Frame

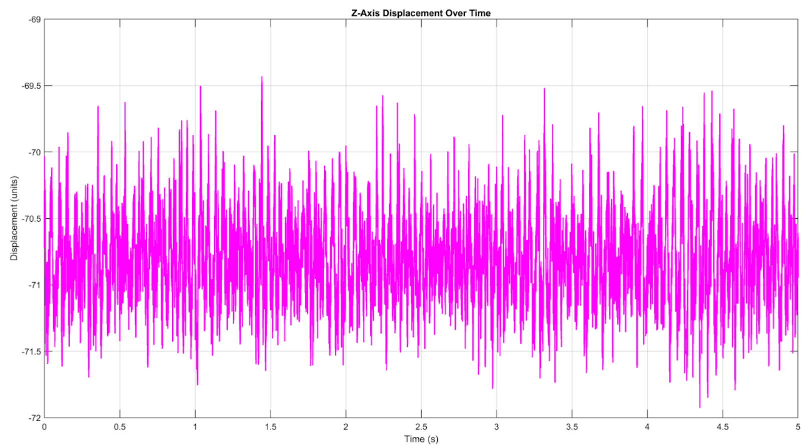

Figure 15.

Peak Detection of Z Axis Relative Displacement During Rack Level Test, Top of Heatsink

Figure 16.

Histogram of Detected Z Axis Relative Displacement Peaks, Top of Heatsink

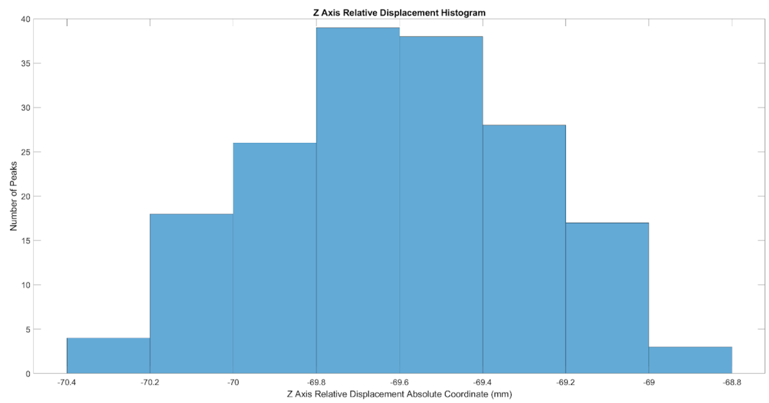

Figure 17.

The results translate to a range of 0.5 to 2.1mm relative displacement. Even with only 5 seconds of data, we already see a normal distribution of the results, which is what we expected from a shaker table random vibration test, generating peaks between +/- 3 standard deviation.

Should damages occur, we can record the precise number of stress cycles and amplitude for failure analysis afterward. Such data can also help us compare different profiles - different ASTM standards, between ASTM and ISTA, or industry standards vs. real world data. The 3D distribution, concentration, and amplitude of stress will help determine whether a test sample is sufficiently stressed compared to real world conditions.

The results were obtained using the simple *findpeaks* function in matlab, but it is possible to look deeper into the time history to estimate the pulse width and the source resonance frequency behind each stress cycle. Accelerometer data can also be analyzed with the 3D displacement side by side to further understand how various modes impact relative displacement in real time. The raw relative displacement data suggests the relationship is not as simple as previously thought.

Zoomed View of Z Axis Relative Displacement

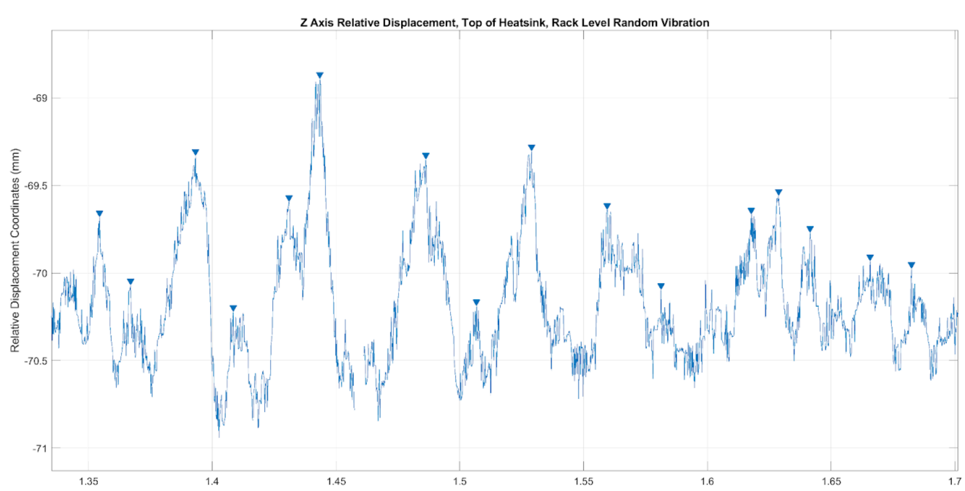

Figure 19.