GOOGLE'S RANDOM VIBRATION TESTING METHODOLOGY, A HIGH LEVEL OVERVIEW

PART 2: SINE VIBRATION OF A MACHINE INSIDE A RACK
REVISION A

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Sine Dwell of Machine in a Rack, 22.61hz, 1.0G

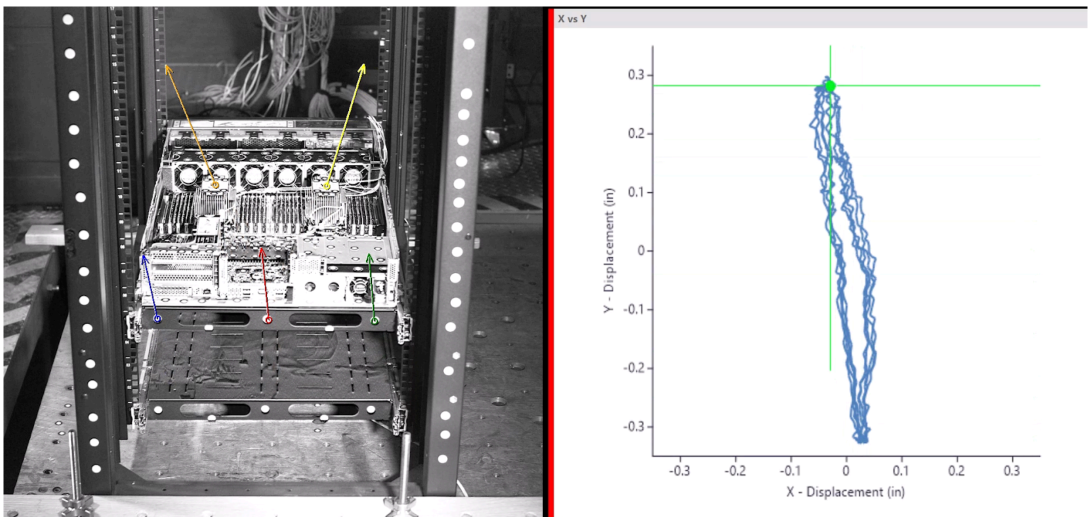

Figure 1.

<u>What happens to the machine when it is installed in a rack?</u>

Factors that contribute toward local component level stress
and failure modes in a fully populated rack

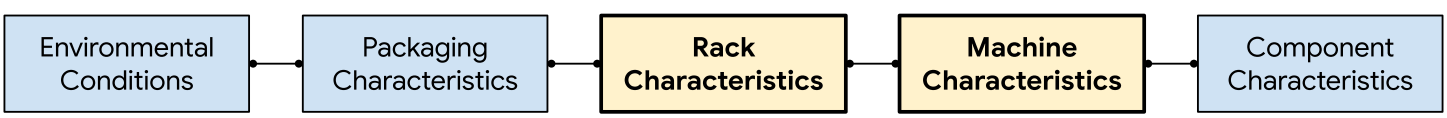

Figure 2.

Now that the measurement methods are introduced, we can quickly continue through the analysis. The same sample unit is mounted inside an OTS 19" Server Rack. This rack is mounted directly on the shaker table without any packaging material or pallet base. It is held down with wood beams and threaded rods.

Lenovo ThinkSystem SR650 V2 mounted inside a OTS 19” Rack on shaker table

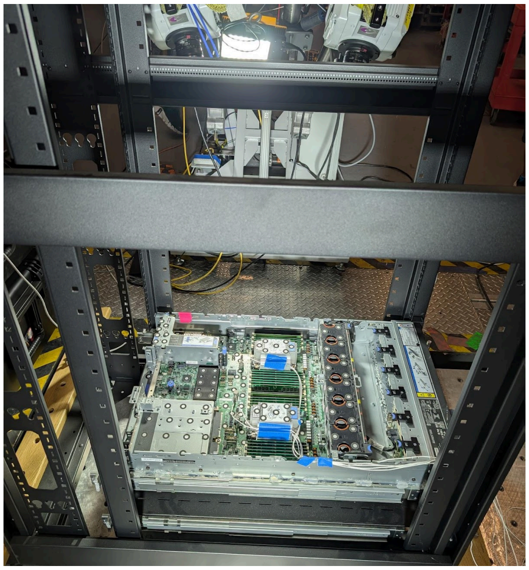

Figure 3.

The same sinesweep is repeated for this setup.

Equipment	Specifications
Electrodynamic Shaker: Unholtz-Dickie, K170 series	48” by 48” head expander, up to 15g (sine and shock), up to 2000hz, up to 2500lbs test unit load
Vibration Controller: Vibration Research VR10500	16 channels, up to 256khz sample rate
Accelerometers: Dytran Uniaxial IEPE accelerometer	Ch 1: Shaker table as reference control Ch 2: Area of the PCB in front of CPU0 Ch 3: Area of PCB between CPU0 and CPU1 Ch 4: Area of PCB in front of CPU1 Ch 5: On top of Heatsink of CPU0 Ch 6: On top of Heatsink of CPU1
Software: Vibrationview 2022 for shaker control, data acquisition, and data analysis	Profile: Sinesweep, 0.2G (zero to peak), 5hz to 500hz, 1 oct/min
Setup Time: 45 mins	

Table 1.

Lenovo SR650 V2 Rack Level Acceleration Transmissibility Profile

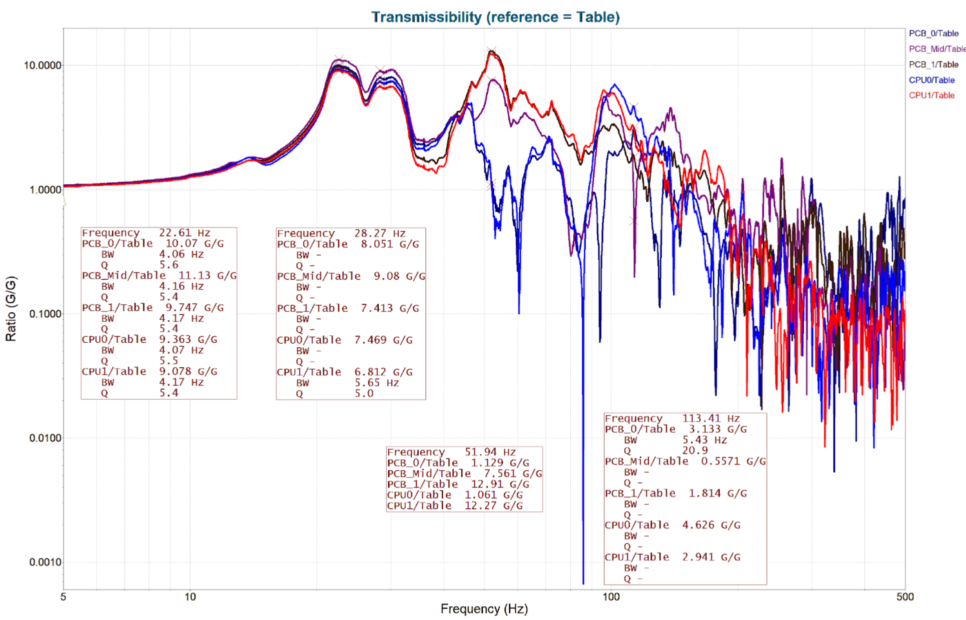

Figure 4.

There is now an additional mode at 22.61hz, one not present at the chassis level sinesweep. The amplification factors are also higher. We need more information to understand the discrepancy. RDI videos are captured for this test setup:

Natural Frequency Evaluation with RDI Motion Amplification

Equipment	Specifications
High Speed Camera: Phantom v2640, 1920 x 1280	4000 frames per second, 0.2 second duration, 2048 x 1536 resolution
Software: RDI Iris MX, Motion Acquisition and Motion Amplification	Profile: Sine Dwell @ 22.61hz & 0.5G, 28.27h & 1.Gg
Setup Time: 45 mins	

Table 2.

We apply a 0.5G Sine Dwell for 22.61hz and 1.0G for 28.27hz, both to the same setup with the same camera position. This allows an apple to apple comparison between the scale of the measurements. We use a higher G level (than the sine sweep) because it generates more movement for the camera to capture - 0.2G is generally very low and difficult to visualize. We also kept 22.61hz to 0.5G because we didn't want to cause any permanent damages to the test setup initially. Generally, we start to get clean displacement data when the g levels are raised to 0.5G to 2.0G (sine dwell). Here is what we observed:

Sine Dwell, 22.61hz, 0.5G

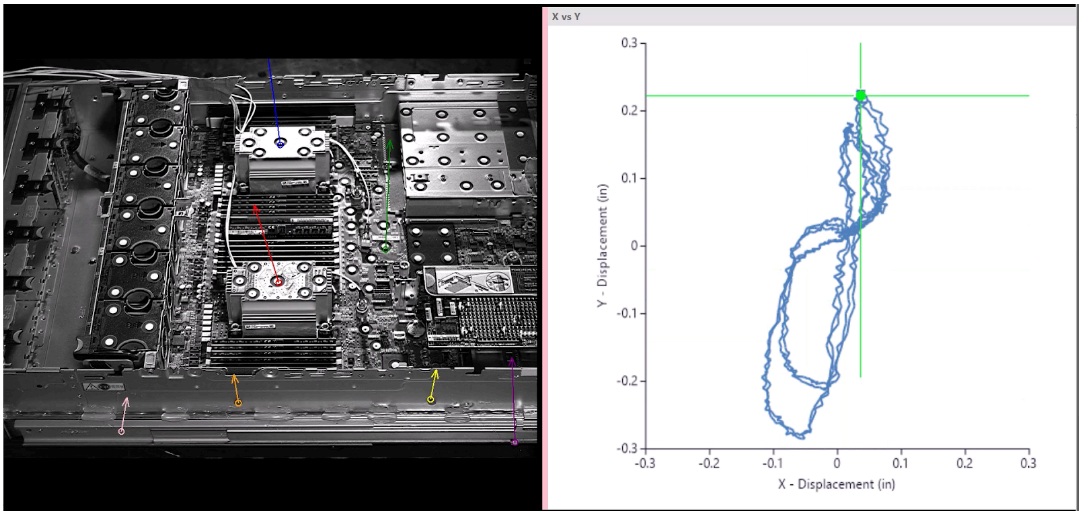

Figure 5.

Sine Dwell, 28.27hz, 1.0G

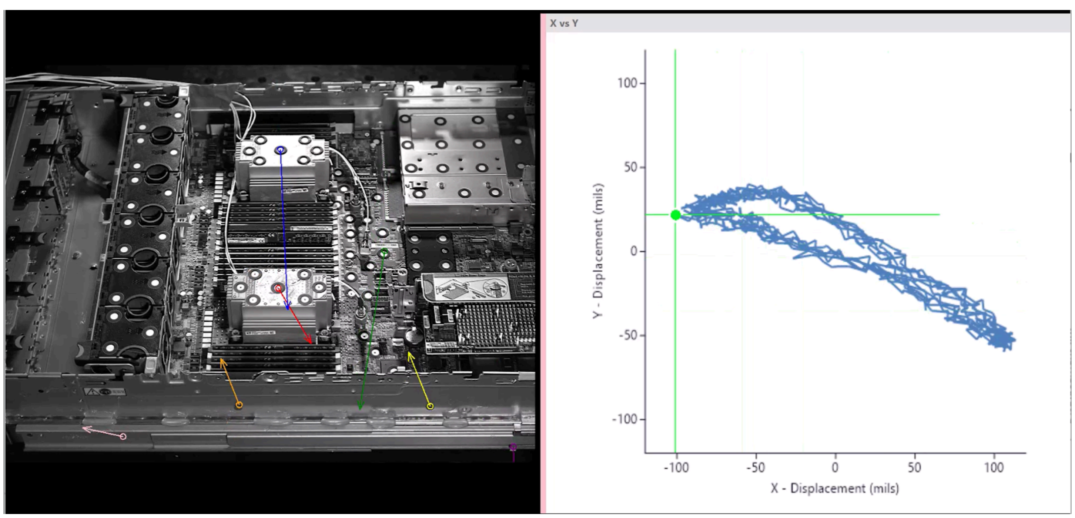

Figure 6.

We took the XY displacement measurement of the pink cursor in the lower left corner in both videos. Ignore the absolute unit of the values for the moment - the image is not calibrated to this particular setup (we will go in depth about this in a future paper). We can however compare the peak to peak values to calculate the scale relative to each other. We find **5 times more peak to peak movement in the Y axis when comparing 0.5G @ 22.61hz to 1.0G @ 28.27hz**.

This phenomena is more clear when viewed from a different angle which includes the movement of the shelf and rack. In this angle, it is even more clear that the shelf experiences significant displacement at 22.61hz.

Sine Dwell, 22.61hz, 1.0G

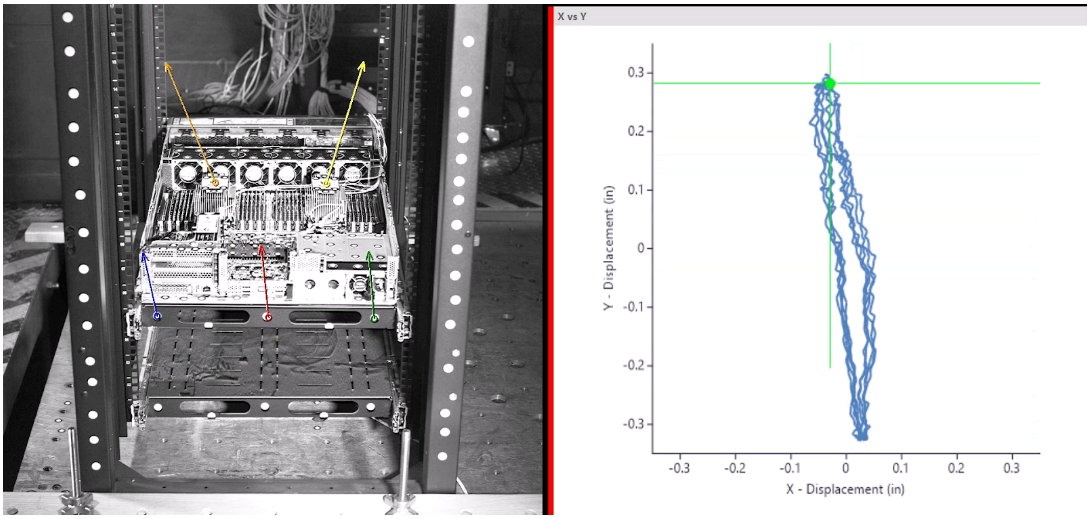

Figure 7.

Sine Dwell, 28.27hz, 1.0G

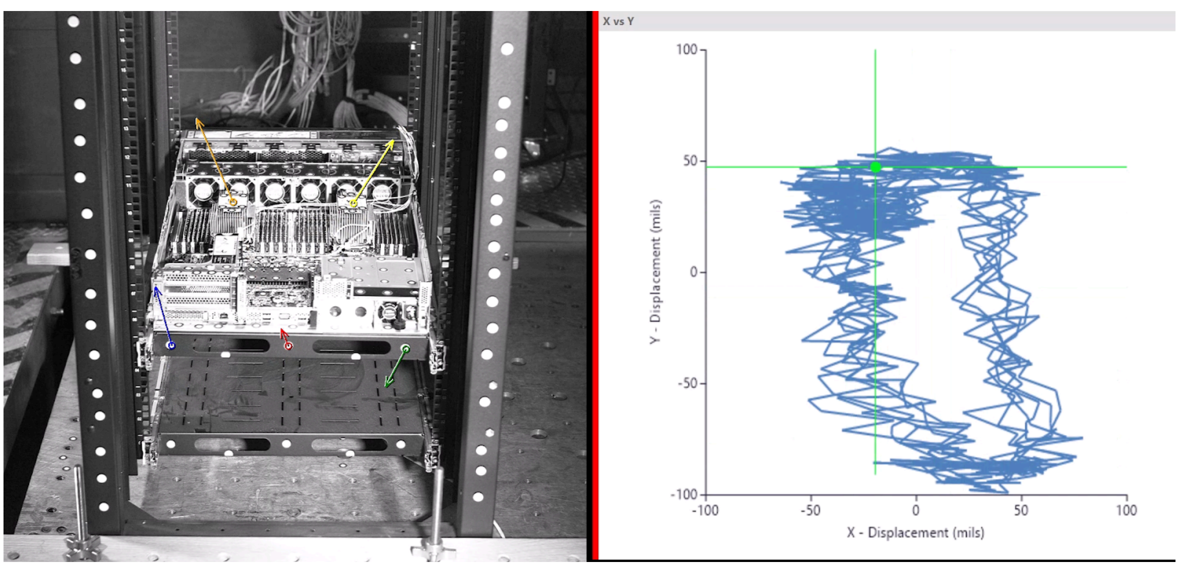

Figure 8.

The structural characteristics of the rack level setup creates a new mode at 22.61hz, which causes more movement. The question is, does this additional mode lead to more relative displacement on the board (which leads to local stress and strain)?

3D Displacement Measurement with High Speed 3D DIC

Equipment	Specifications
High Speed Camera: Duo Phantom v2640	4000 frames per second, 0.2 second duration, 2048 x 1536 resolution
Calibration Target: Zeiss Calibration Object	CP20 Panel / CP20/350, 20.5” x 18.5”
Software: Zeiss Inspect Correlate	Profile: Sine Dwell @ 22.61hz & 0.5G, 28.27h & 1.0G
Setup Time: 3 hours	

Relative Displacement to CPU1, @ 22.61hz and 0.5G

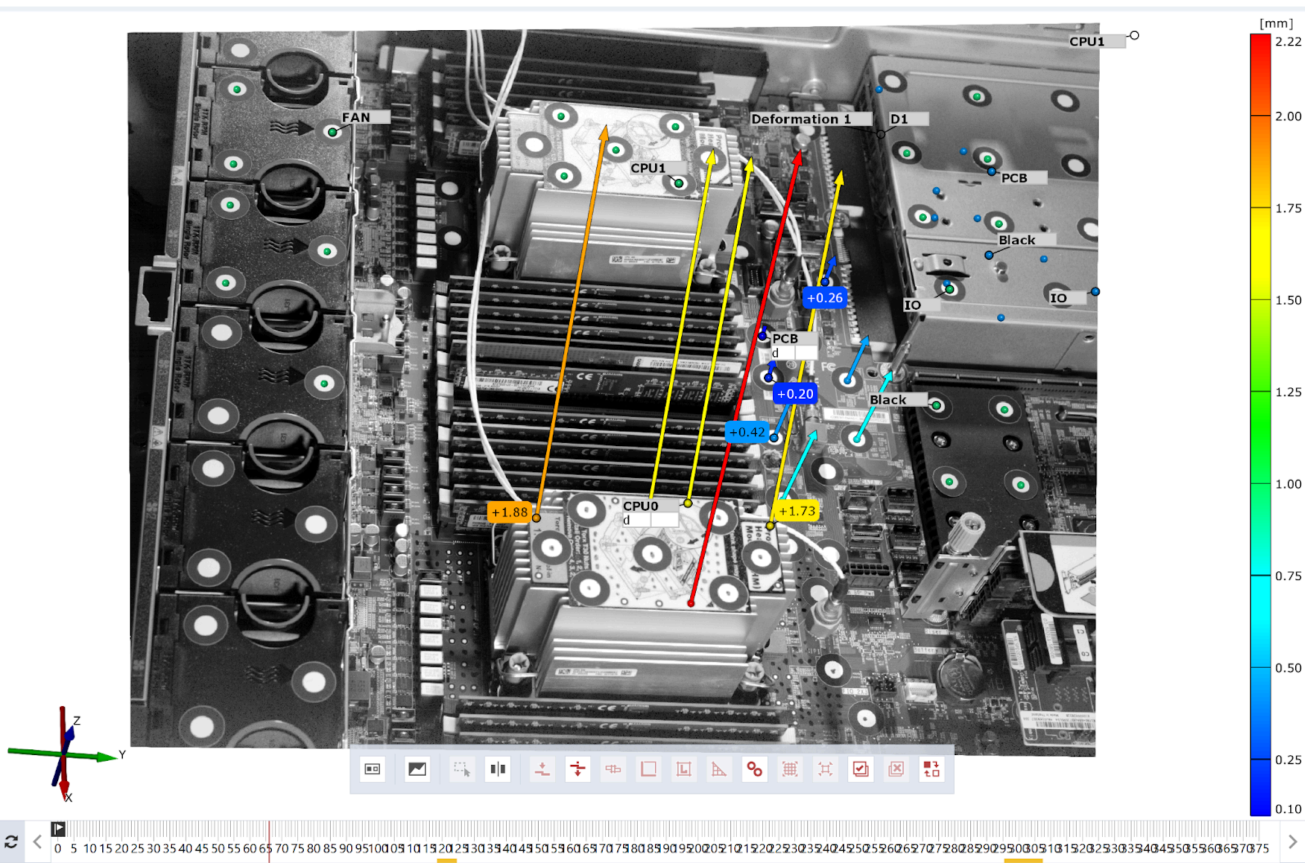

Figure 9.

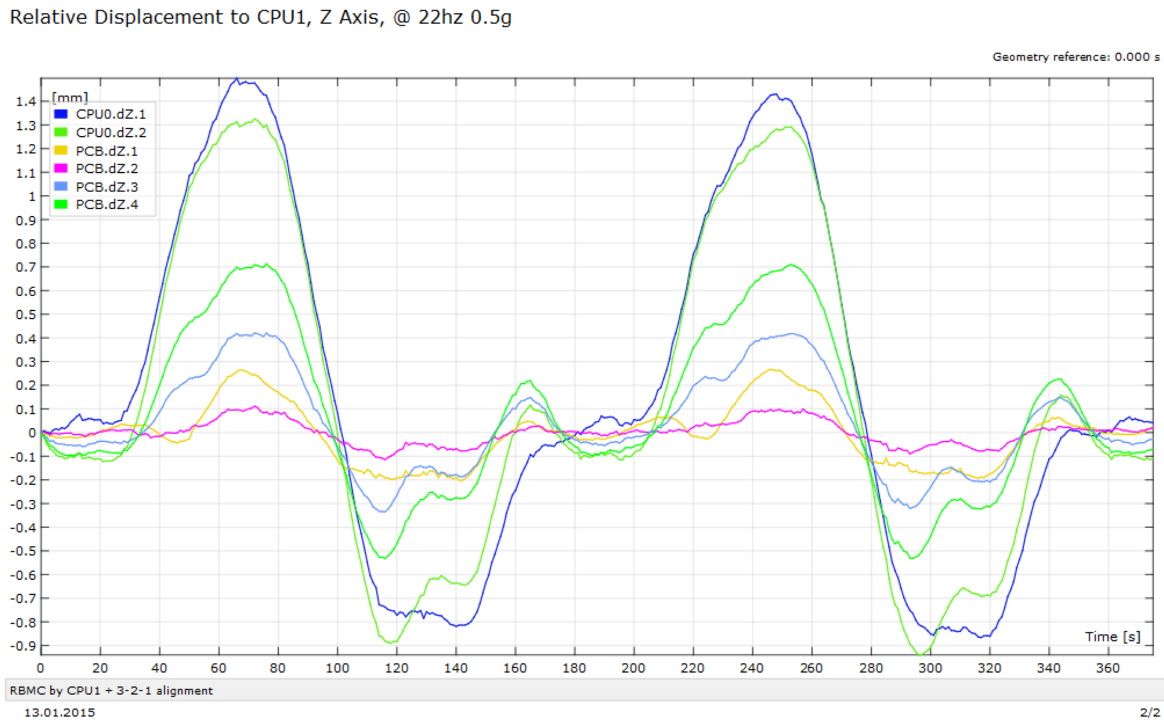

Figure 10.

Relative Displacement to CPU1, @ 28.27hz and 1.0G

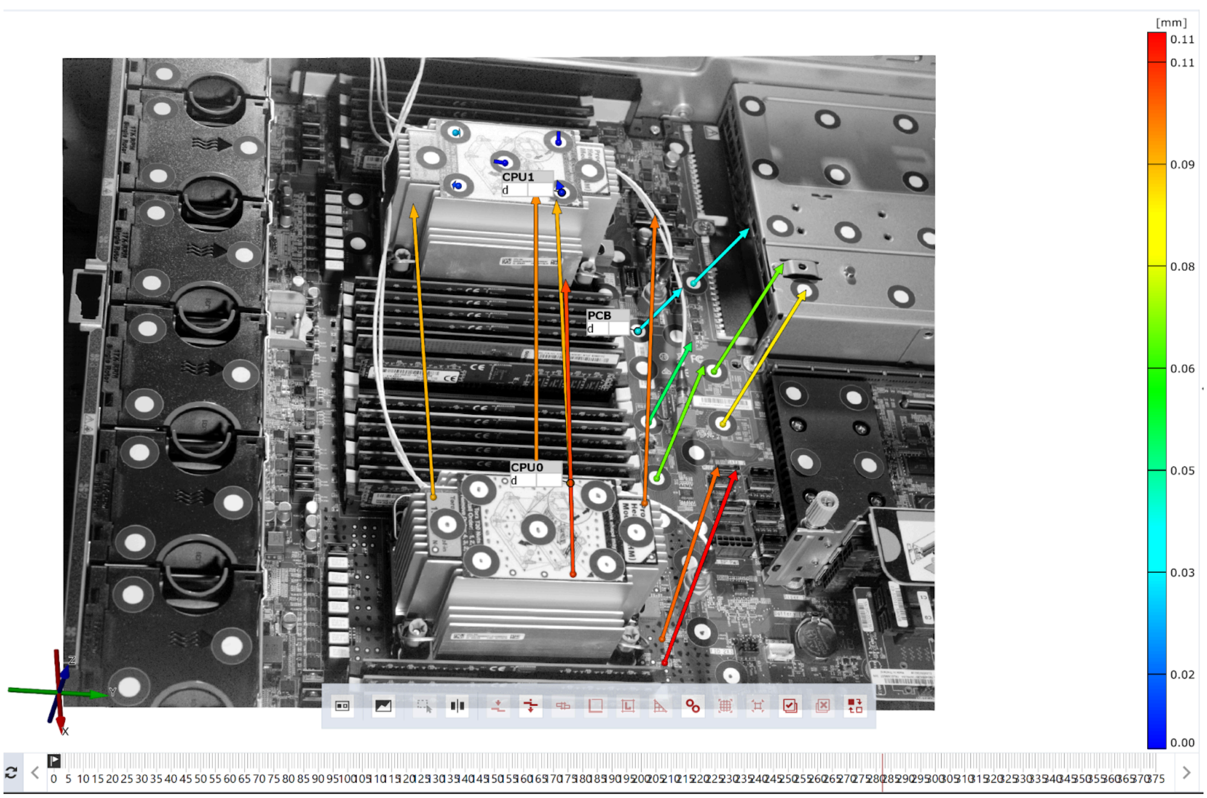

Figure 11.

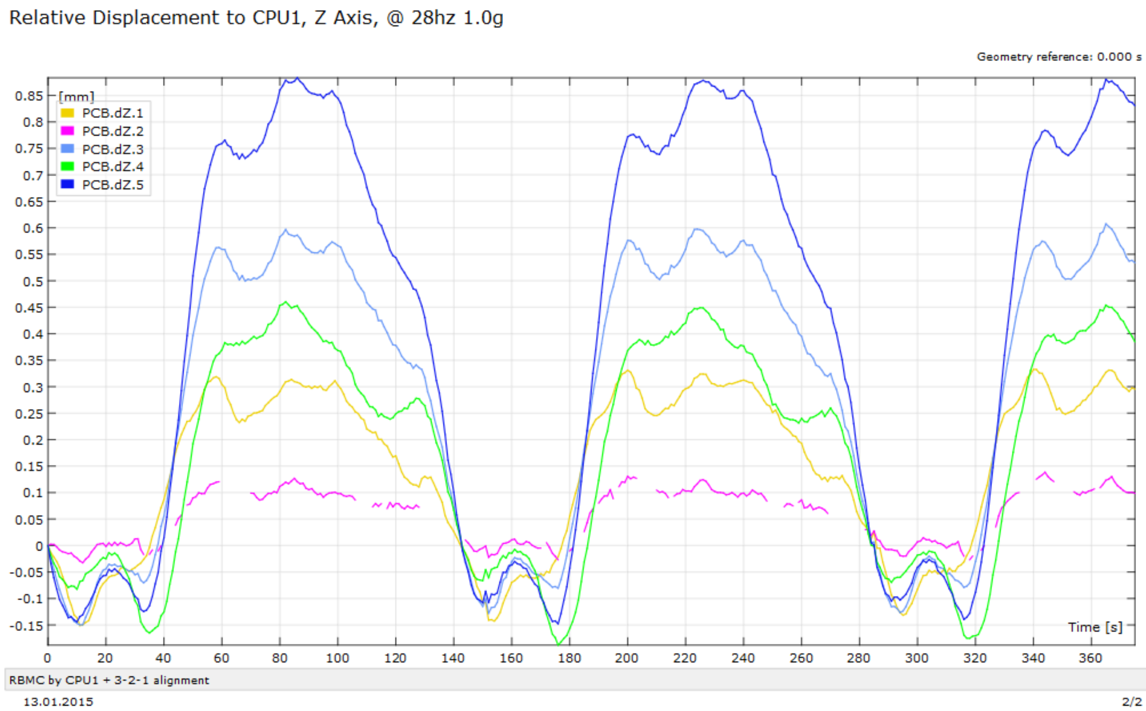

Figure 12.

A quick note about the setup - because the unit is higher on a populated rack, it is harder for the stereo cameras to have visibility of the entire unit plus the shelf without major modifications to the setup. We don't have markers on the table or rack structure to zero out the shaker's movement (we will in the future), but what we can do is calculate displacement relative to specific components to see if objects are moving relative to each other.

This was done on CPU1 Heatsink, the one further away from the screen. The measurements show the boards and CPU0 heatsink are in fact moving relatively to CPU1 Heatsink for both natural frequencies - a maximum of 2.4mm between the PCB and CPU1 Heatsink for 22.61hz, and 1.0mm for 28.27hz.

Intuitively, it makes sense. As the shelf bounces up and down, the board and the heatsink continue to travel upward or downward to their limits as the shelf begins to change direction. The result is a deflection very much like the unit's first mode at 28.27hz.

Bigger Picture

Google’s Rack Level Sine Vibration Analysis

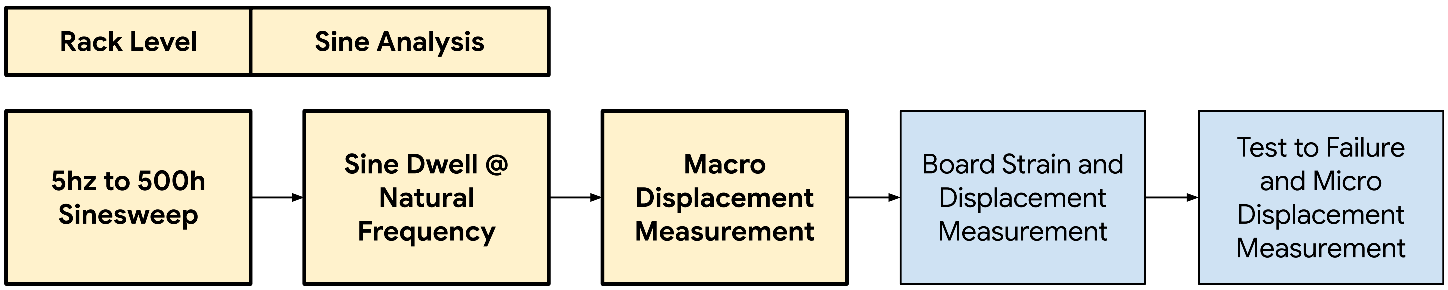

Figure 13.

We’ve just completed a rack level sine analysis. We build on top of chassis level results to understand how the presence of a rack changes dynamic behavior. In this example, the combination of chassis and rack created a new natural frequency at 22.61hz, which created more opportunities for deflection and local stress and strain during random vibration and shock events.

Having an understanding of each layer is important because they produce actionable results for the design team. For example, the following areas of focus should be considered if the design team wants to mitigate shock and vibration induced stress:

1. Changes to the shelf and rails to reduce the amount of flexure at its natural frequency
2. Changes to the machine itself to further mitigate local stress and strain resulted from such deflection
3. Potential packaging solution that reduces energy at the examined natural frequencies

No matter which direction the team takes, the same measurement and analysis should be repeated to verify the effectiveness of a solution, using acceleration and relative deflection measures as metrics.

Still, we can’t assume fixes for sine vibration is enough to reduce board deflection for random vibration and shock events. We have to verify it with actual testing. We also need to spend some time understanding how products and PCBs behave under random vibration conditions because the interaction is more complex. With ever increasing complexity of internal structures of AI hardware, there is no telling what we will find as we once again attempt to look inside the black box.

We will need tools specifically tailored for random vibration, where future papers and experiments will spend a lot of time.