A HIGH LEVEL OVERVIEW OF POPULATED RACK TRANSPORTATION VIBRATION

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Populated Rack Transportation Vibration Overview By Layers

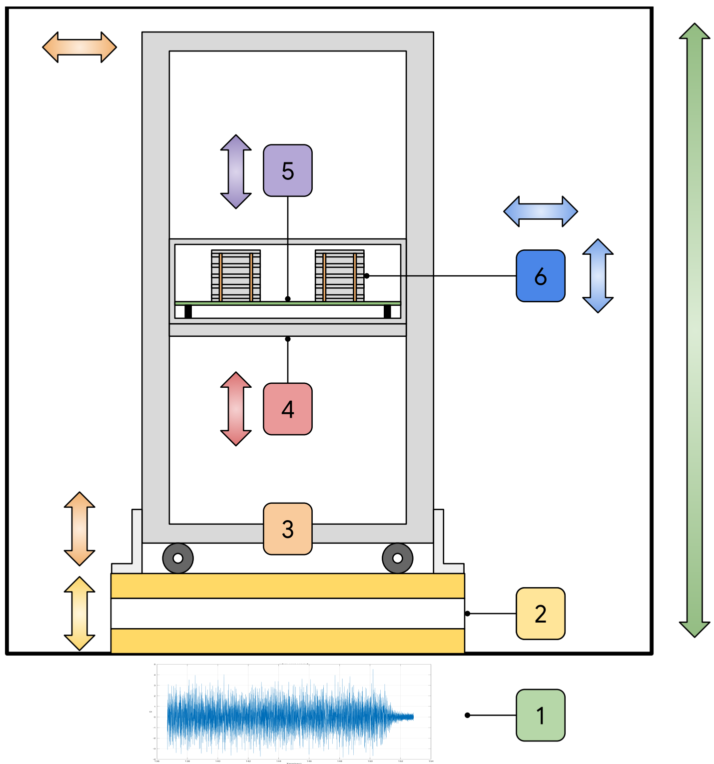

Figure 1.

1	Vibration Conditions	Result of movements of vehicle, tire, suspension, trailer, and road conditions.
2	Packaging	Transforms environmental vibration into rack vibration.
3	Rack	Hold all the parts inside the rack together. Has its own bending and swaying modes, as well as its own failure modes.
4	Shelf or Rail	Transforms rack vibration into shelf or rail vibration.
5	PCB	Transforms rack vibration into board vibration.
6	Heatsinks	Example of masses that influence the dynamic of the board. Has its own swaying modes that add to local stress and strain.

Table 1.

Google's Open Source Random Vibration Testing of Fully Populated Racks with Off-The-Shelf Data Center Hardware

Challenges of Traditional Random Vibration Test Methods

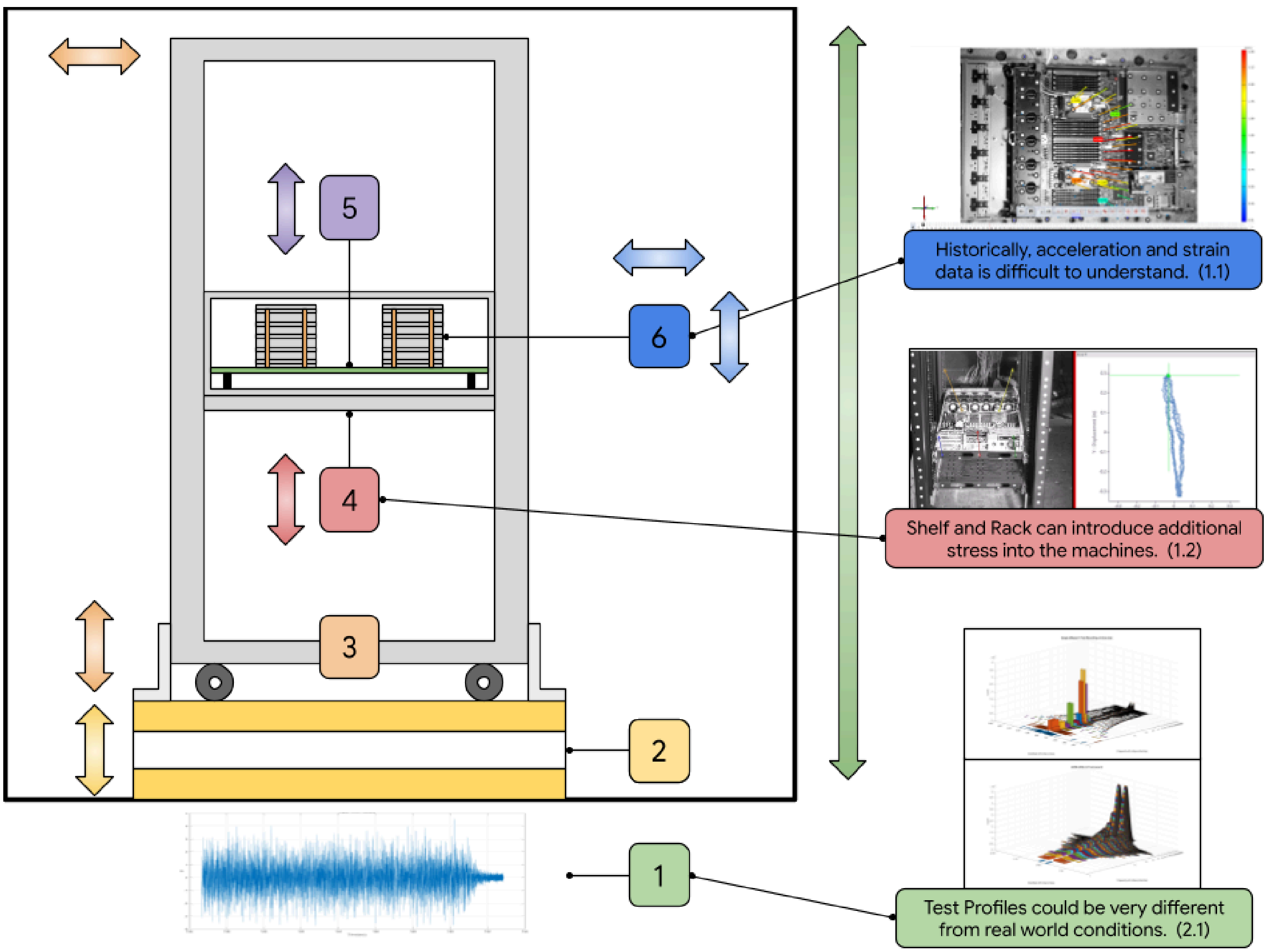

Figure 1.

It is common practice for fully populated racks to be shipped to data centers as a single unit. Many companies are known for doing it - IBM, Sun Microsystems, Cisco, Amazon, Meta. But when this topic is researched, there is a surprisingly limited amount of information or literature available on the engineering behind this practice, even less when testing (which is my main focus at Google) is concerned.

It took many years for me to learn how to test a fully populated rack from scratch, and I am still learning. But I know enough now to know there must be a better way to maintain this body of knowledge, to develop this area of expertise for those who follow. Building an open source project around it is the best I can come up with, and it appears just in time for the explosion of demands as AI data centers are rushed to be built around the world. Perhaps we can take this opportunity to get enough folks interested to build something that will last.

Random vibration testing of fully populated server racks is as complicated as the internal structure of the silicon inside the racks themselves, so this is a huge undertaking. We will do what we've always been taught since the first day of school - breaking it down into smaller, more manageable pieces, and we will take this one day at a time.

Let's look at an overview of the problem.

Scenario #1: Board Deflection as a result of input vibration

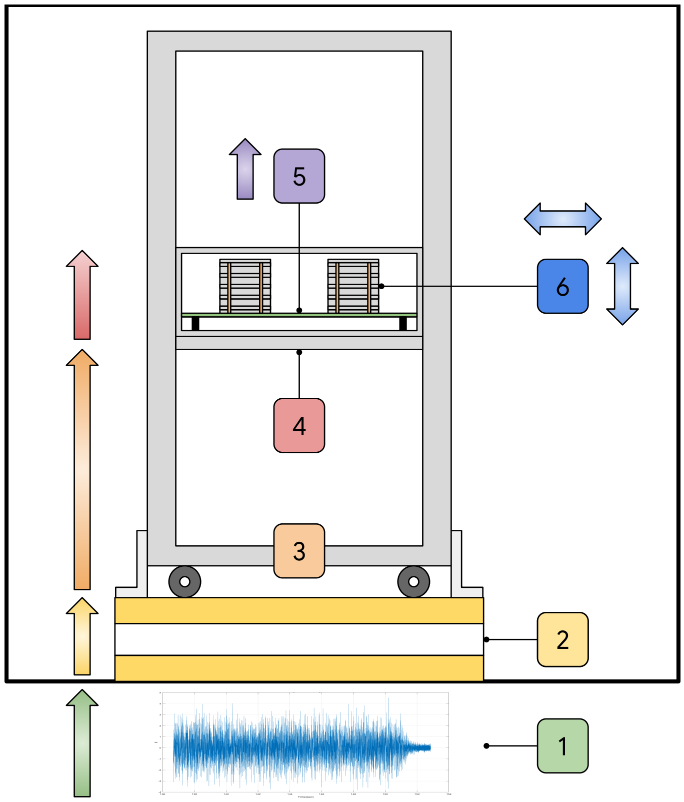

Figure 2.

Figure 1 depicts a simplified version of a fully populated rack being shipped in a vehicle. It has a rack with a single 2 socket machine installed in it. It is mounted (with large angled irons) on top of a wooden pallet with foam as the material of vibration isolation, and the whole structure is loaded into a cargo truck for transportation.

As the truck travels, vibration is generated by the movement of the vehicle, tire, suspension, trailer, and the conditions of the surrounding environment. This vibration gets amplified by the pallet and rack structure, causing deflection of the printed circuit board inside the machine, and ultimately leads to mechanical damage and machine failure at data centers.

It's easy to image board deflection as a result of input vibration. Vibration (1) travels through the packaging material (2), through the rack structure (3), through the shelf/mounting rail (4), through the machine into the PCB (5), and pushes the two large masses (heatsinks) (6) up and down. In this scenario, isolation in the form of packaging material makes sense - the packaging material absorbs the input vibration and reduces the overall movement of the rack.

Scenario #2: Board Deflection as a result of free fall shock impact

Shock Spectrum Equation: Fig. 1 is the SDOFs model to explain the shock spectrum where:

y is the shock motion applied to the bogey or heavy wheeled foundation.
x is the absolute displacement of the SDOF mass
z is the relative displacement, x - y.

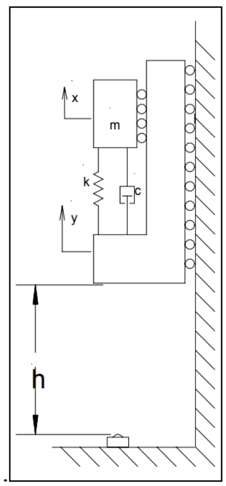

Figure 1. The shock table wheeled bogey with a single degree of freedom system (SDOFs) attached.

Figure 3.

An alternative view in Howard A. Gaberson's "Pseudo Velocity Shock Spectrum Rules For Analysis of Mechanical Shock" [1] describes shock impact as a result of the free fall of a shock table wheeled bogey. The bogey hit the ground after falling distance h, mass m wants to continue the motion, and is caught by the spring-damper system underneath. Potential energy is converted to spring energy, converted to kinetic energy, converted to potential and spring energy, and the mass-spring-damper system continues to vibrate until all the energy is dissipated through heat and noise.

This scenario is quite relevant to our populated rack - if for whatever reason the rack is picked up and dropped (handling shock during loading and unloading, for example), the masses inside our machine would be caught by the spring damper system underneath, which is the printed circuit board. The energy would dissipate over time, and the storing and releasing of spring energy would lead to concentrated stress and strain at critical components, causing mechanical damage if the amplitude is sufficient.

In this scenario, a dampening material in the form of packaging might help to catch the fall of the wheeled bogey (our rack), but by the time the energy is fully dissipated, a lot of interaction would've already happened between the heatsink, PCB, and the metals surrounding it, leading to damages.

Scenario #3: Board Deflection as the result of resistance of continuous changes in momentum

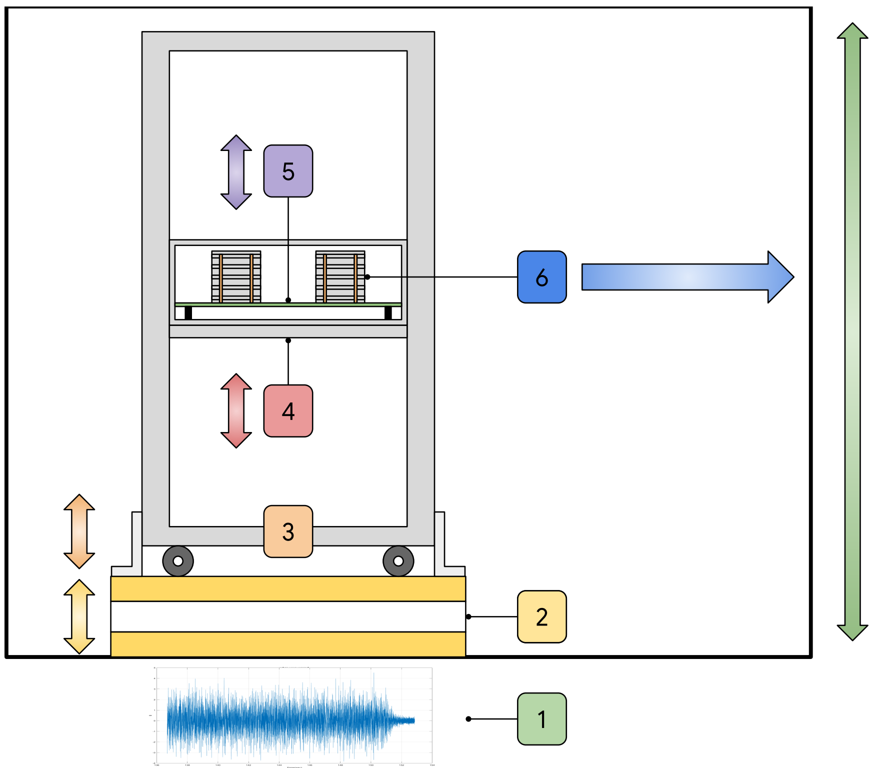

Figure 4.

Let's take this analogy one step further. Let's say the vehicle is moving evenly on a road. The fully populated rack is traveling forward through space, and the road suddenly becomes wavey. The masses (heatsinks) inside the machine want to continue traveling forward in a straight line, but the condition of the road causes the trailer to move up and down, which causes the rack and packaging material to move up and down, which causes the shelf/rail and machine chassis to move up and down. The heatsinks resist these movements as if the machine is pushing against it, and this leads to deflection of the PCB, which leads to damages.

Depending on the input vibration and road conditions, this storing and releasing of potential, kinetic, spring, and strain energy may continue until the vehicle comes to a complete stop.

In the real world, fully populated racks experiencing some combination of all three scenarios, but most people are only aware of scenario #1 and #2. The physical interactions involved are subtle, but packaging materials in scenario #3 would mean very little if materials external to the heatsinks suddenly change directions for whatever reason.

Further investigations of behaviors and mitigation strategies might be needed if the amplitude of stress is sufficient, or if the internal components are very sensitive to mechanical stress.

Common issues in random vibration testing of fully populated racks

Beyond the simple misconception of the problem, the testing of a fully populated rack has always been a challenge, no matter how experienced you are. A server rack is typically big and heavy, it takes a lot of work to assemble, prepare, and perform the test, and the huge amount of potential failures in a complex rack system is daunting.

Each layer of the stack also have issues that could make the work even more difficult:

1	Vibration Conditions	1. Test Standards are very different from real world conditions in terms of amplitude, frequency, and cycle count. See Paper 2.1.
2	Packaging	1. Packaging is designed to absorb vibration and reduce the amount of energy that reaches the products. However, for populated racks, wooden crates or traditional packaging often becomes a second source of movement that leads to deformation of components and boards, particularly when there is a lack of proper isolation due to cost, material, and size constraints.
3	Rack	1. Racks not designed for transportation in fully populated configurations often experience failure modes unique to the rack itself. Mounting bolts, welds, rivets are all potential sources of failure that could lead to catastrophic outcomes in the field.
4	Shelf or Rail	1. Shelf or rails not designed for transportation in fully populated configurations often experience failure modes unique to the shelf or rail itself. 2. Shelf or rails often become an additional source of movement that leads to additional deformation of components and boards.
5	PCB	1. Historically, it is difficult to measure board level deflection in random vibration even with the most advanced measurement capabilities. This leads to all kinds of misconception of board level behavior in complex structures such as a populated rack. See Track 1 papers on a high level overview of this topic.
6	Heatsinks	1. Large masses like heatsinks often have unexpected dynamic behaviors in a complicated structure like a populated rack. Isolation solutions designed to slow down rack level movement may end up generating more movements at the heatsinks, leading to additional local stress and strain. Advanced measurements are needed to check for such issues.

As we move forward with the project, we will revisit many of these topics in a more focused fashion to understand their implications using real world examples.