Multi-Exciter vs. Single Exciter Cantilever Beam Test

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When we consider what multi exciter vibration testing is, we need to understand that it has different meanings and ideas. This paper is going to look at multi exciter in 3 axis form, or 3 degrees of freedom (3 DoF.) This is not when you take a single axis shaker and perform testing in sequence in X direction, Y direction, and Z direction. This is 3 exciters set up on a test rig to perform all 3 axes of testing at one time. A simple project to help identify the difference will be evaluated in this short paper. We will take a simple cantilever system of a tensile bar, also known as a dog bone and vibrate it at its first fundamental mode for 1 million cycles per direction, or failure, whichever comes first.

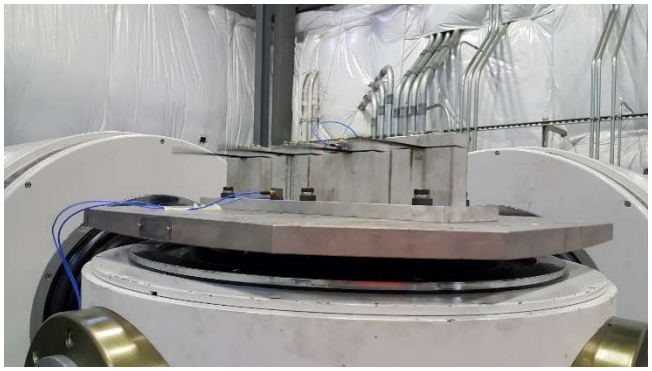
The dog bone will be a type 1 tensile bar made of BASF Ultramid Nylon. They will be clamped on one end, and the fixture will handle 4 parts at one time, see Figure 1. Will run 2 sets of each idea to create more confidence in the run and confirmation of the findings. The runs will consist of running single axis X-axis, Y-axis, Z-axis, then a set with Z-axis, X-axis, Y-axis. Then finally a set on the 3 DoF rig. All of the system are from Dongling Technologies. The single axis system is a ES-50L-S4-445 with slip table, and the 3 DoF machine is a 3ES-50-HF-400.

Before the experiment of running the single frequency at a given load, a sine sweep was done in each independent direction, and 3 DoF to find the target frequency and for 3 DoF the phase that produced the maximum energy. At this point, we should point out why this was done. With 3 DoF, we need to think of each direction as a vector, so we will have magnitude and direction. The total force on felt on the part, is the summation of the forces in each direction. With a control system for MIMO, we can look at the vector sum of each axis and this will help determine the maximum vibration energy at the point where we took the reading. The frequency from the sine sweep was found to be 37.8 Hz. To simplify the experiment, we set up a Dwell profile at 37.8 Hz, and 6 g magnitude at the control point. In the following tables, will be the findings of the control and measurement at the part for the energy in G rms acceleration. The main mode is like that of a diving board, the beam will bend near the clamped end.

Figure 1: Set up of fixture on 3 DoF

Below is a table of the Single axis inputs with the corresponding off axis. The Bold is the driven axis of control. The values are given in rms.

Position:	Drive	Part	Position:	Drive	Part
X-axis	**4.24**	**4.36**	X-axis	0.0424	0.263
Y-axis	0.0425	0.015	Y-axis	0.0424	0.0538
Z-axis	0.0424	0.129	**Z-axis**	**4.24**	**4.15**
Position:	Drive	Part			
X-axis	0.0424	0.00795			
Y-axis	**4.24**	**4.38**			
Z-axis	0.0424	0.0325			



Below is a table of the energy at the dog bone accelerometer on the 3 DoF machine.

0°	phase		***70°***	***phase***	
x	3.23	rms	***x***	***3.35***	***rms***
y	3.68	rms	***y***	***3.61***	***rms***
z	3.44	rms	***z***	***3.49***	***rms***
Total	10.35	rms	***Total***	***10.45***	***rms***
25°	phase		80°	phase	
x	3.25	rms	x	3.34	rms
y	3.66	rms	y	3.59	rms
z	3.44	rms	z	3.44	rms
Total	10.35	rms	Total	10.37	rms
45°	phase		90°	phase	
x	3.29	rms	x	3.33	rms
y	3.64	rms	y	3.57	rms
z	3.47	rms	z	3.4	rms
Total	10.4	rms	Total	10.3	rms
60°	phase				
x	3.32	rms			
y	3.63	rms			
z	3.47	rms			
Total	10.42	rms			

So, for the 3 DoF test run, we ran it coupled, used 70° phase with a COH of +95% at the drive. The test was run with the X-axis, Y-axis, then Z-axis first, then the run with the Z-axis, X-axis, Y-axis. Then finally the 3 DoF with all axis at once. The 1st and 2nd runs of parts went the full 3 million cycles. Upon further investigation, the parts that went the X-axis, Y-axis, Z-Axis, has slight surface cracks while the 2nd run of Z-axis, X-axis, Y-axis did not. With the 3 DoF, the parts started to crack significantly around 700,000 cycles and all failed before 900,000 cycles.

You might wonder why. Well, if we look at the idea of vectors, in single axis, we use only one vector, so the total would only be one direction of energy. And to correspond, the 3 DoF is 3 vectors of energy, creating a summation of energies, greater that of any one axis. The second thing to remember is the summation of 2 vectors from two planes, will now have magnitude and torque. When setting up these input vectors and creating the largest amount of overall output energy in the 3 directions, we get a twisting action in the dog bone. This twisting action, along with the larger overall magnitude of energy is what effecting the degeneration of the dog bone. These types of forces are very hard to produce and control on a one axis vibration system.

The outcome of testing is not just pass or fail, we must look at each test independently and evaluate what is corresponding to real world conditions. The major mode was that of Z-axis, that is the bending moment like a diving board. If one ran that first, the Z-axis, then the other 2 axes after, one may not see any possible problems with the test subject as in the experiment. While if you run the two off-axis of the main mode which in this case is the Z-Axis, you can possible see some minor problems due to the

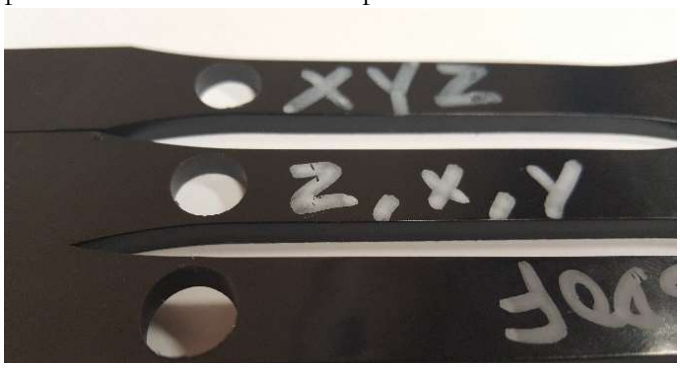


Figure 2: Example of all parts.

deuteriation of the dog bone. This outcome is most likely caused by the 2 off axis creating some degradation in the part, then the main mode axis will accelerate the already degraded area. And in this case caused some surface crack in the part, where the bending moment was the greatest. The expectation of failure in the 3 DoF was something we expected, but did not expect in the first 1,000,000 cycles.

So when looking at the 3 DoF testing, we see that it is important to remember that it is the summation of energy in 3 axis. This testing did not only shorten the time by the idea of 1,000,000 cycles per axis, but also in the amount of time. The average was about 80% of a normal time to do the 1,000,000 cycles in a single axis. This means we can truly say that the difference between a single axis test sequencialy, and 3 DoF, is the 3 DoF is 1/3 the time. I believe further investigation on this must be done, because it also shows that the amount of total energy will be greater, and either total time or energy will need to be looked at. Taking a normal sequencial test and just putting it on a 3 axis can have an unexpected outcome on the test results, so we must be careful and not just throw a test from single axis to 3 DoF without some forthought.

Figure 3: Broken 3 DoF parts.

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