Faster, Better, Cheaper Vibration Testing With Electrodynamic Shakers

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MECHANICAL SHAKERS

At one time, 1950 and earlier, the only shakers available were mechanical. Some, as in Figure 1, are still in use for simulating transportation. One axis, vertical, is usually considered sufficient. A typical top frequency is 60 Hz. Little instrumentation is involved. Easy movement of a manually-moved 1/16 inch shim under the package indicates that the shaker has thrown the package that far into the air.

Figure 1 - Mechanical vibrating platform (courtesy LAB)

Yet even in simulating transportation, a few advanced firms are recognizing that in the "real world" fore-and-aft and lateral vibrations occur at the same time as vertical vibrations. Their laboratories are employing recently-developed 3-axis mechanical shakers, as in Figure 2.

Figure 2 - Three-axis vibrating platform (courtesy Kokusai Keisokuki)

ELECTROHYDRAULIC (SERVOHYDRAULIC) SHAKERS

Electrohydraulic (EH) shakers are used in many seismic and land vehicle applications, up to 500 Hz. Figure 3 shows a typical single-axis system that can only deliver last-century *sequential*-axis (X, then Y, then Z, three tests) testing. At left is the hydraulic supply. At right is the controller.

Figure 3 - Servohydraulic vibration system (courtesy Lansmont)

Figure 4 shows EH shaker-driven NEBS (Network Equipment Building Systems) last-century *sequential*-axis seismic testing (three tests required).

Figure 4 - Horizontal NEBS testing (courtesy Dayton T. Brown)

Figures 5, 6 and 7 illustrate much newer *simultaneous* multiaxis testing, faster (one test instead of three) and much more realistic. North-south earth motions differ from east-west earth motions which differ from up-down earth motions.

Figure 5 - Seismic investigation of residence (courtesy Mitsubishi Heavy Industries LTD.)

Figure 6 - Earthquake simulation (courtesy ANCO Engineers)

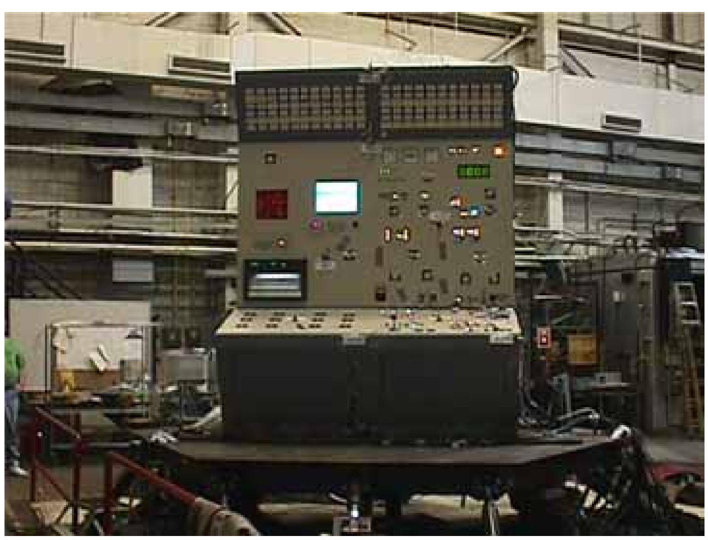

Figure 7 - Earthquake simulation (courtesy ASTRO NUCLEAR DYNAMICS, Inc. and ANCO Engineers)

Multiaxis shaking of a nuclear power plant controller, as in Figure 7, is intended to uncover any controller weaknesses that would lead to failure during a real earthquake. That controller will be needed if the reactor is damaged and must be shut down.

Figure 8 shows an excitation platform driven by multiple EH shakers; for realism, motion must be simultaneous multiaxis.

Rail transport damage once led to many new vehicles arriving at California dealers with batteries fully discharged. Why? To find out, an observer traveled with the next shipment. Mile after mile, the horns on all those automobiles were blowing. On a setup like Figure 8, the right laboratory combination of vibration frequency and force led to horn blowing. Investigation showed a resonance in the horn relay attachment bracket. Bracket redesign fixed the problem, as was proved by further shake testing.

Figure 8 - Platform simulates rail or other transport (courtesy MTS)

Figure 9 illustrates multiple EH shakers simulating road inputs not to platforms but rather into automobile axles via force-sensing wheels.

Figure 9 - Road simulation on automobile (courtesy MTS)

ELECTRODYNAMIC SHAKERS

Electrodynamic (ED) shakers typically permit last-century single-axis-at-a-time vibration testing to 2,000 Hz. Figures 10 and 11 show one aspect of typical ED shaker construction, their suspensions: the spring-like elements that support shaker armature + test load + load attachment fixture. These elements also guide the armature along its single axis.

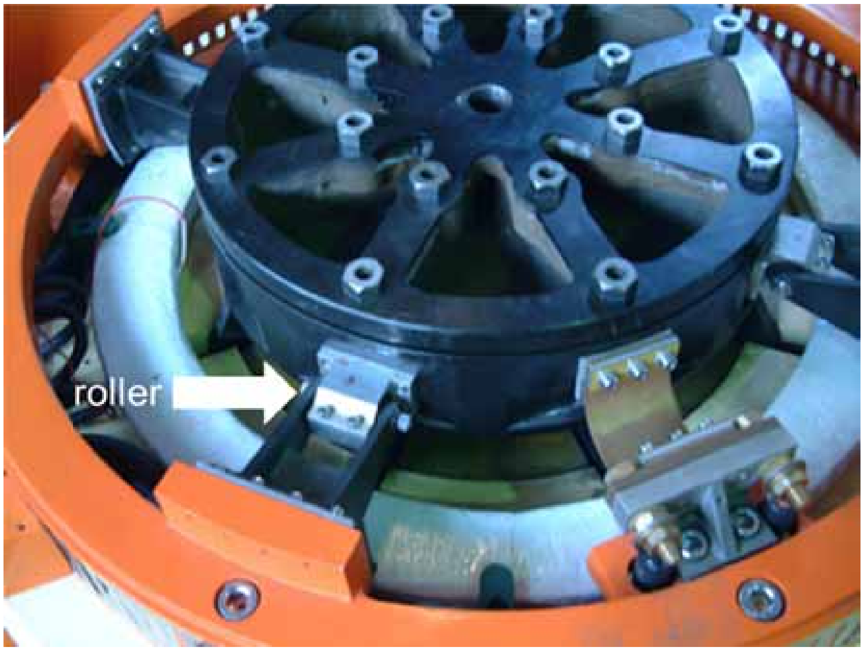

Figure 10 - Electrodynamic shaker armature and suspension (courtesy Dynamic Solutions)

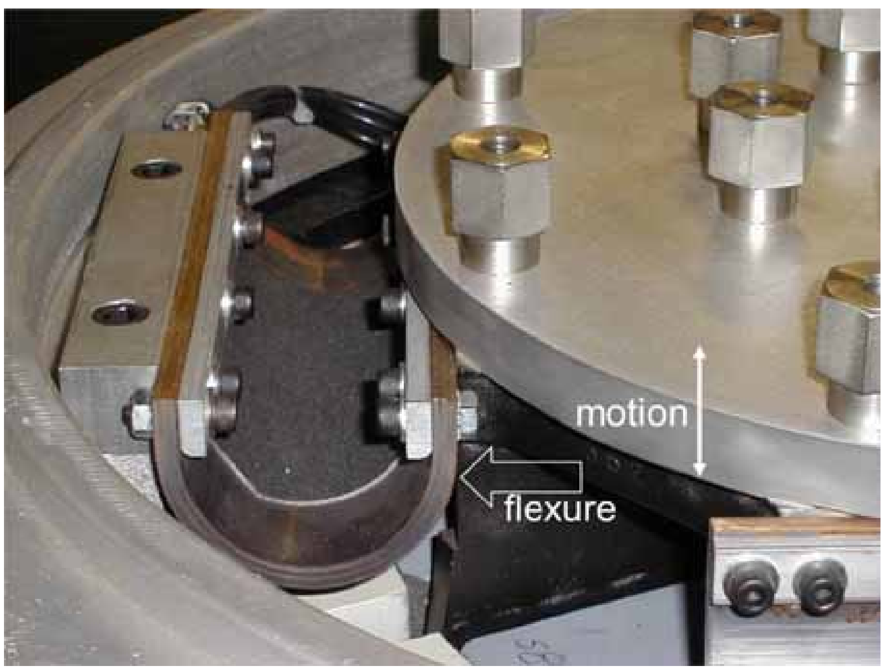

Figure 11 - Electrodynamic shaker armature and suspension (courtesy Ling Electronics)

"TILT" FIXTURING STILL SINGLE AXIS

Figures 12, 13 and 14 illustrate a misleading attempt to achieve simultaneous multiaxis testing through tilting either the device under test (DUT) or the shaker. The motion, obviously, **i**s still single axis.

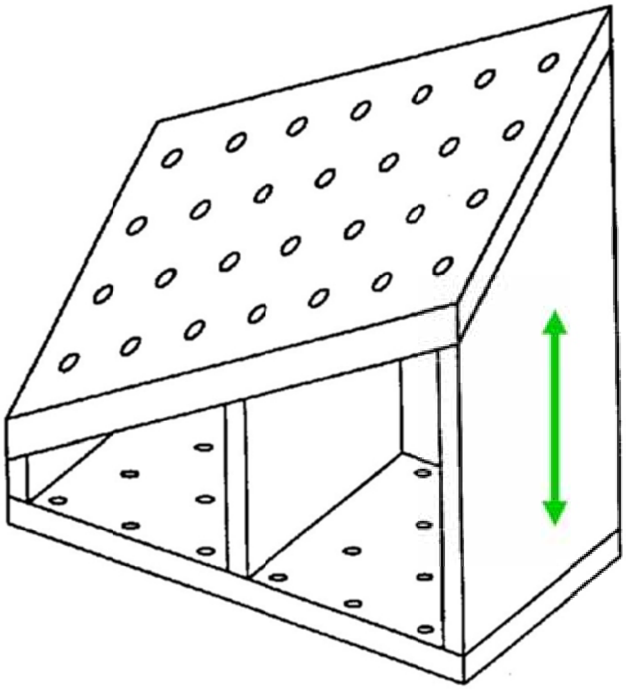

Figure 12 - Tilted fixture does not multiaxis test

Figure 13 - Some labs tilt their test articles (courtesy Hong Liu)

Figure 14 - Tilted single-axis shaker maintains normal gravity loading of the test article (Courtesy Quanta Labs)

PNEUMATIC RS OR REPETITIVE SHOCK

Figures 15, 16 and 17 illustrate pneumatic RS or Repetitive Shock hammers driving a platform that also functions as the bottom of a thermal test chamber. This is the least expensive way to get simultaneous multiaxis excitation. Unfortunately, little control is possible over the spectral content of the excitation. An afternoon's repeat of a morning test will differ markedly.

Figure 15 - RS actuators combined with thermal chamber (courtesy QualMark)

Figure 16 - Pneumatic RS units excite the softly-sprung platform (courtesy GHI)

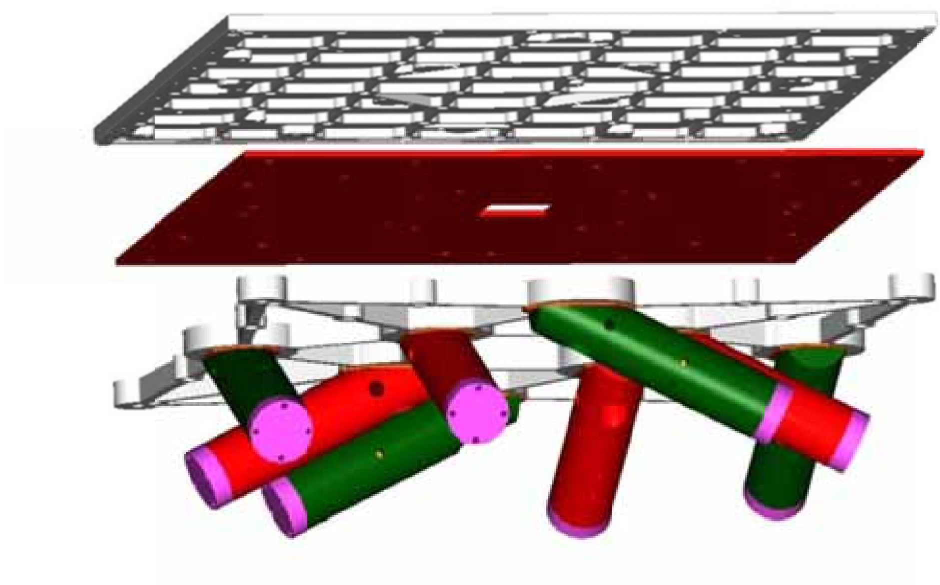

Figure 17 - Pneumatic RS actuators excite relatively rigid table. Observe the thermal barrier which protects the RS units from thermal extremes. (courtesy QualMark)

SIMULTANEOUS MULTIAXIS ED SHAKING

Thus far, no US firm has offered a three ED shaker array similar to the imported array shown in Figures 18, 19, 20. Why not? Probably because US military and commercial purchasers of reliable electronic and other hardware do not yet understand the benefits of *requiring* simultaneous multiaxis shaking. It is now *permitted* by Test Method 527 of MIL-STD-810G. It should be *required*.

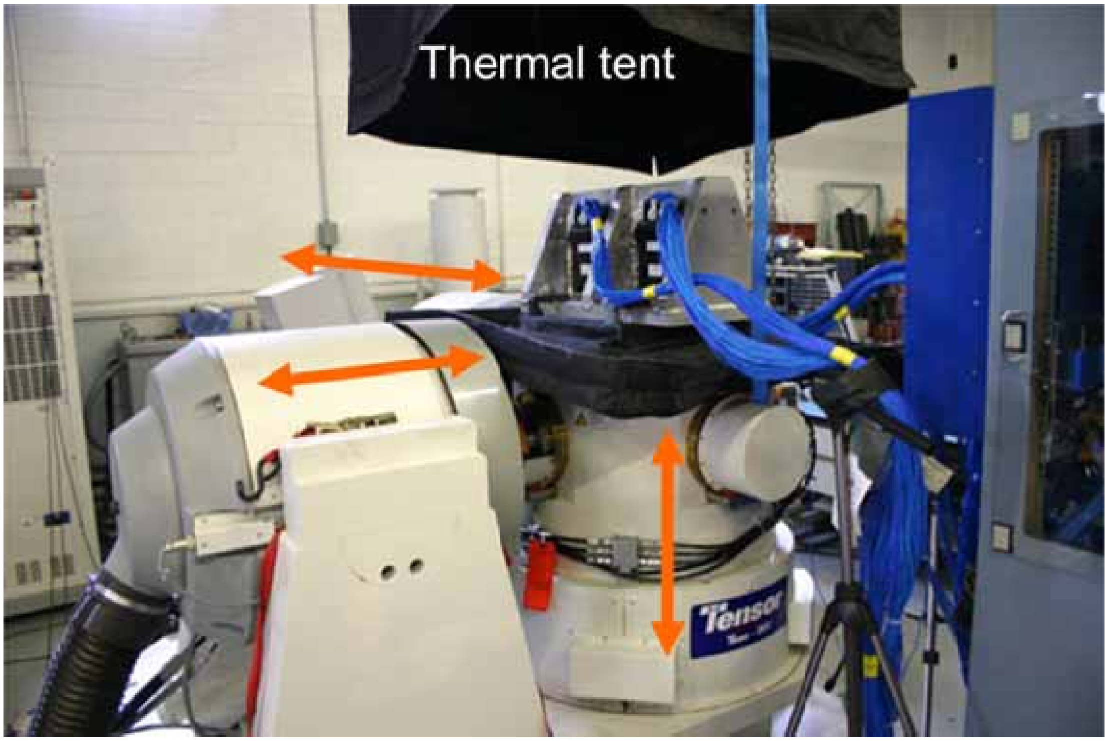

Figure 18 - Tri-axial automotive electronics shaking, common in Japan, slightly recognized in the US (courtesy IMV, Visteon and Spectrum Technologies)

Figure 19 - Triaxial shaking of automobile headlamps (courtesy Spectrum Technologies)

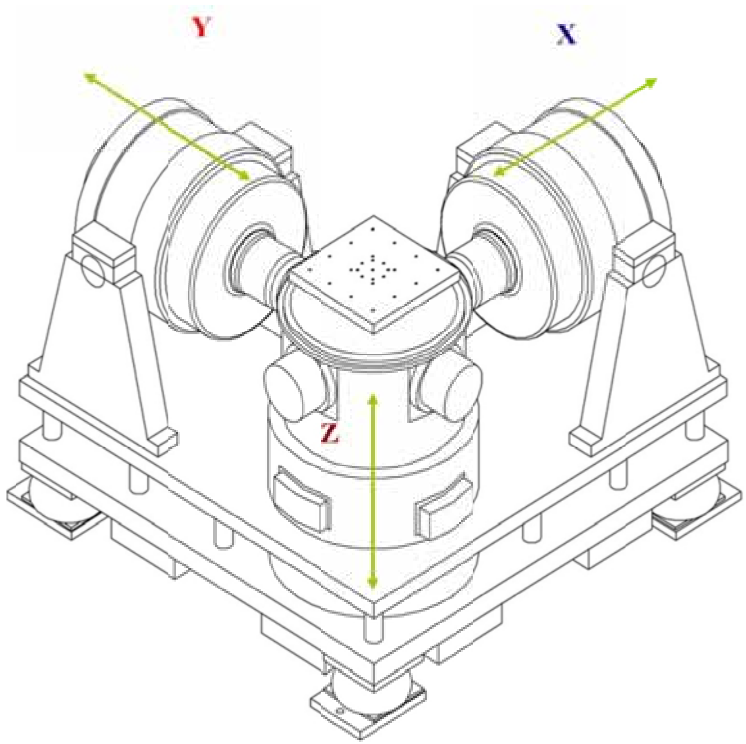

Figure 20 - Three single-axis shakers multi-axis drive a common load (courtesy IMV)

Figure 21 shows IMV's method of avoiding damage (to the individual ED shaker units) that would be caused by the other two ED shakers.

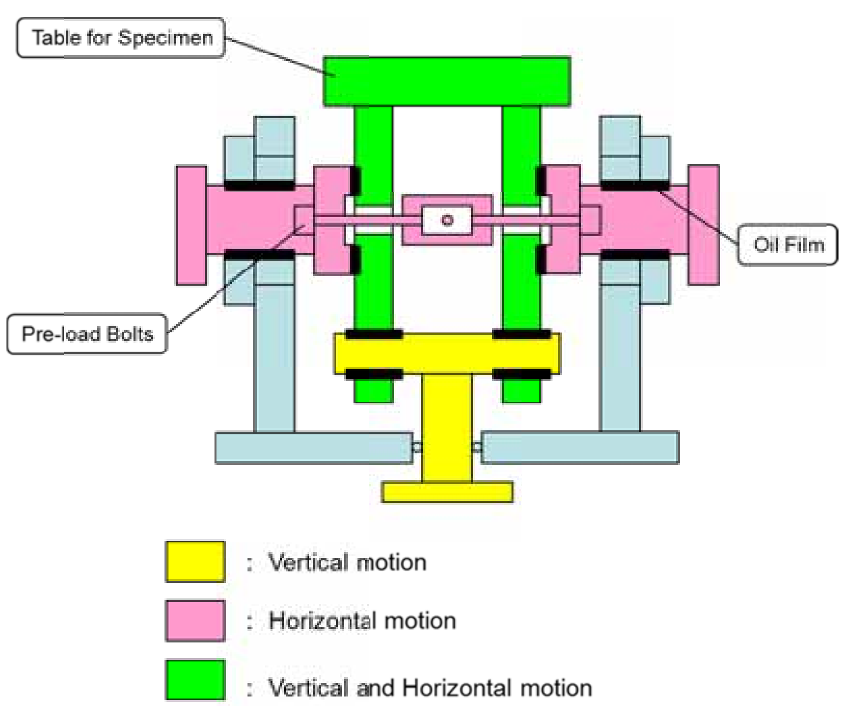

Figure 21 - IMV calls this motion-combining unit their ICCU (courtesy IMV)

Video clip 6 shows 45^{o} horizontal motion possible with equal in-phase sine excitation of the two horizontal shakers. Video clip 7 shows circular flat motion possible with equal out-of-phase excitation with the two shakers. I wish we could show you these video clips here. The reader can visualize a third axis excitation with the vertical shaker in each case: diagonal resultant in Video Clip 6 and spherical resultant in Video Clip 7. The reader can also visualize possible failures in his own hardware (from 3D excitation) *not* discoverable by single-axis-at-a-time last-century excitation.

Another three-shaker overseas offering is shown in Figure 22.

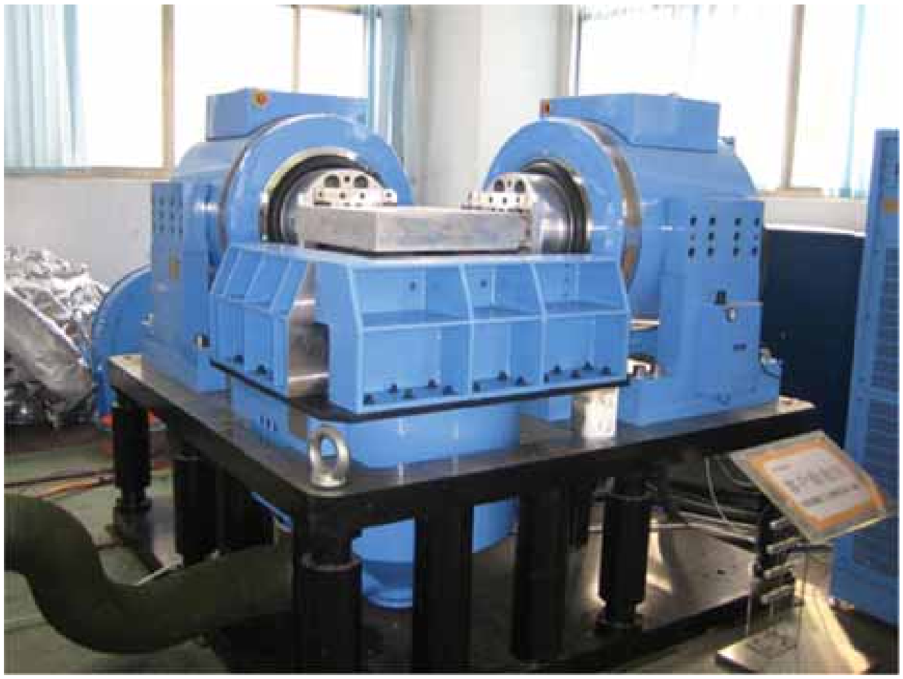

Figure 22 - Three Chinese shakers (Courtesy Dong Ling & Spectral Dynamics)

FASTER, BETTER, CHEAPER VIBRATION TESTING

Faster? Certainly. One test instead of three.

Better? Yes. There has been documentation of weaknesses not found by X then Y then Z testing but found by X + Y + Z testing.

Cheaper? Yes. Consider the time savings of one test instead of three. Consider the design, fabrication, physical evaluation and storage of one fixture instead of three. Consider failure avoidance in the field.

ASSEMBLE THREE EXISTING ED SHAKERS

Granted that purchase of three shakers + three power amplifiers will seem expensive. This author remembers selling their first ED shaker to numerous firms and agencies 1954-1961 (before he became a teacher). Many of those firms and agencies found so many vibration-induced weaknesses in their hardware, using that one over-busy shaker, that they quickly bought additional shakers. The author predicts that simultaneous multiaxis shaking will quickly "catch on" in the US as it appears to have done in Asia.

But suppose that we happen to have (or can cheaply obtain) three conventional single-axis shakers. Can we put them together, as did the US Army, Air Force and Navy? Let's see how they did it.

The Army Research Lab at Adelphi, Maryland had a problem. A piece of equipment was failing in service but the lab, using one shaker, one axis at a time, could not replicate the failure. Somehow ARL got funding to add two more shakers, as in Figure 23. That and several other “mysterious” failures could *now* be replicated. Simultaneous shaking at the Army’s White Sands Proving Ground, Figure 24, followed.

Figure 23 - Pioneer three-shaker 3DoF realization (courtesy US Army)

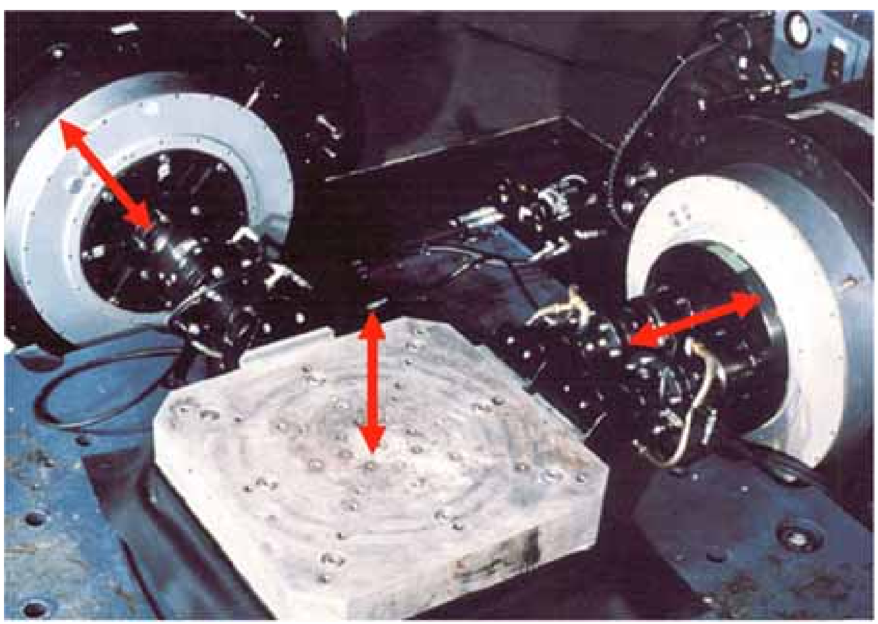

Figure 24 - Three-shaker 3DoF realization (courtesy Team Corporation and White Sands Proving Ground)

The USAF, by contrast, wanted 6DoF and connected together eight existing ED shakers, as shown by Figures 25 and 26. Their lab, in Utah, is operated by Boeing.

Figure 25 - USAF Multiaxis ED shakers (Courtesy U.S.A.F.)

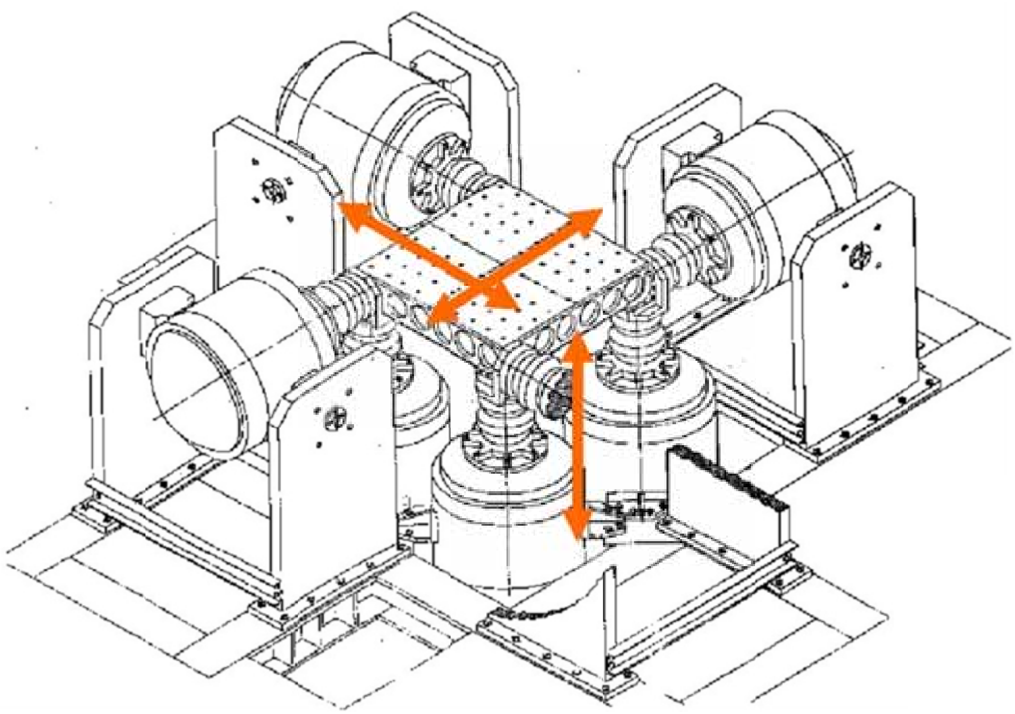

Figure 26 - USAF Multiaxis ED shaker (Courtesy U.S.A.F.)

In both Figures 24 and 26 we see spherical hydrostatic bearings that protect the individual ED shakers from damage by the other ED shakers.

In Figure 27 we see three existing ED shakers assembled for 3D shaking. Figure 28 shows an earlier proposal that would have required a pit for the vertical shaker. Instead, Keyport opted to attach the array to an isolated inertia mass, as seen in Figure 30.

Figure 27 - Three-shaker Navy 3DoF realization (Courtesy NUWC Keyport and Baughn Engineering)

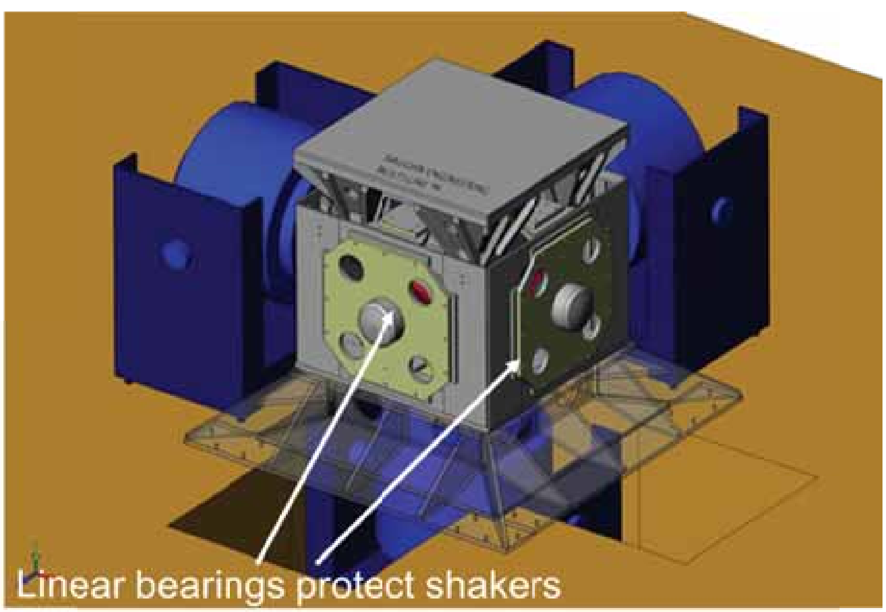

Figure 28 - Proposed installation; not utilized (Courtesy NUWC Keyport and Baughn Engineering)

Figure 29 – Three shakers are attached to isolated inertia mass (Courtesy NUWC Keyport and Baughn Engineering)

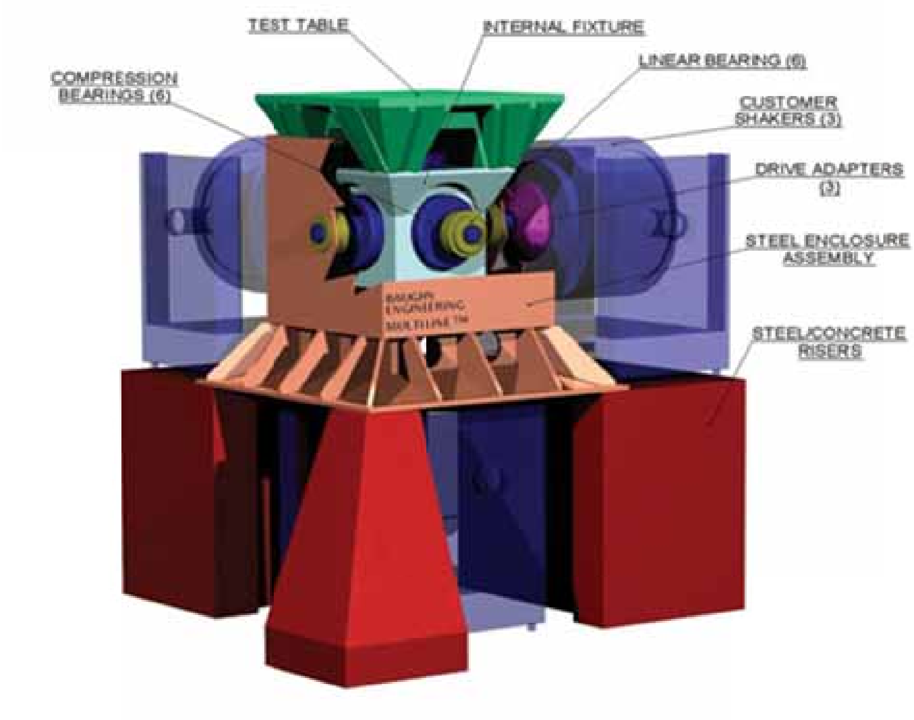

Figure 30 – Explanation of joining the three shakers (Courtesy NUWC Keyport and Baughn Engineering)

Common to Figures 23, 27, 28, 29 and 30 is a sliding action that protects the individual ED shakers from damage by the other ED shakers.

Figure 30 offers additional details of the Keyport installation. Dark green and light blue parts move in 3 axes. Red and orange parts and the olive green journal bearings are stationary. All dark blue parts move along a single axis. Figure 30's supplier points out that this "combiner" unit can be used with EH shakers.

Figure 31 - Approximate height of new lab floor (Courtesy NUWC Keyport and Baughn Engineering)

With the vertical-axis shaker above the lab floor, a higher personnel floor was needed in 2005, as suggested by the broken line of Figure 32 and by Figure 33, which appeared as in Figure 34 in April 2006 as the front cover of *TEST Engineering & Management* magazine. That issue contained an article describing the Keyport system in some detail.

Figure 32 - New lab floor in place (Courtesy Test Engineering Magazine)

Figure 33 - *TEST Engineering and Management* front cover; www.testmagazine.biz.

Figure 34 shows earlier single shaker vertical single-axis excitation of fixture and torpedo. The torpedo needed to be supported from above, as when carried by torpedo bomber aircraft. (courtesy NSWC Keyport)

Readers can envision, above the new floor, a thermal chamber that accommodates the fixture and torpedo of Figure 29, now multi-axis.

CONCLUSION

I ask that audience members and readers exert some effort in influencing prime contractors and the MIL services to *require* simultaneous multiaxis shaking.