Simultaneous Multiaxis Shaking

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The nearly-60 year history of mechanical, then electrohydraulic (EH) or servohydraulic then electrodynamic (ED) shakers, is traced, emphasizing that all are single-axis devices, poorly simulating a multiaxis world. Sequential axis shaking has long been the norm. Simultaneous multiaxis vibration testing of entire land vehicles, using multiaxis EH shakers, has become common. However, shake testing of electronic and other assemblies for land, sea and air vehicles, using ED shakers, mostly remains sequential.

A very few US military establishments have obtained and then joined several ED shakers, so they could perform simultaneous multiaxis shaking. Their success has led to the new Test Method 527 in the late 2008 "G" revision to the venerable Military Standard 810. The paper closes with a look at overseas (Japan and China) factory assembly and commercial use of ED multishaker arrays.

Mechanical shakers
In the beginning (until about 1950) all vibration testing (more or less sinusoidal, single frequency at a time) was performed on mechanical shakers. Unbalanced rotors spun at the desired frequency, typically 10 to 60 Hz, producing vibration along a single axis. Devices under test (DUT) were sequentially vibrated in their X, then their Y, then their Z axes, three tests. At least one generation of test engineers knew nothing but sequential axis testing.

Is it possible to mechanically vibrate products randomly? And simultaneously in multiple axes? A year ago I would have said no, but that was before I heard about Kokusai in Tokyo, www.kokusaiusa.com, who sent me Figure 1 and a video clip concerning their servomotor drives, capable of both sine and random shaking.

Figure 1 - Sine and random shaking are possible with multiple axis servomotors. The author added three bidirectional arrows. *courtesy Kokusai*

Electrohydraulic (EH) shakers
These are also called servohydraulic shakers. The frequency range is 0 to perhaps 500 Hz. High pressure oil forces a piston to move within a cylinder, and the piston in turn vibrates the DUT, sometimes directly as in Figure 2, but sometimes via an intermediate platform, as in Figure 3. Note, in Figures 2 and 3, that multiple shakers are used to create multiaxis vibration. Vehicle multiaxis shaking, which all of us feel in our passenger cars, is well established, world wide, in the automotive industry.

Figure 2 - Multiple servohydraulic shakers excite an automobile, simulating a variety of road and off-road inputs during various driving maneuvers. *courtesy MTS*

Figure 3 - Multiple servohydraulic shakers drive a platform that simulates railcar vibrations during shipment from factory to dealerships. *courtesy MTS*

Many ancient and unrealistic test procedures still call for single-axis-at-a-time shaking, sine or random, and are easily satisfied with older systems such as are suggested by Figures 4 and 5.

Figure 4 - A servohydraulic shaker, center, drives a platform to which DUTs will be attached. Note the reaction mass against which the shaker pushes. At left is an electric motor-driven pump and oil reservoir, while at right we see digital shaker controls. *courtesy Lansmont*

Figure 5 - A servohydraulic shaker conducts a horizontal NEBS (Network Equipment Building Systems) single axis seismic shake test. Later the cabinet (telecom equipment) will be rotated 90o. Still later it will be vibrated vertically by another shaker. *courtesy Dayton T. Brown*

Electrodynamic (ED) shakers

Finally, let us consider ED or electrodynamic shakers, whose operating principle is the same as with electrodynamic loudspeakers. Alternating current for the moving coil (on the armature) is developed by a power amplifier. The sine or random vibration test frequency range is typically 20 to 2,000 Hz.

There is a temptation to tilt the DUT with the fixture of Figure 6 or to tilt the shaker as in Figure 7 and to call the DUT motion multiaxis. This author calls the DUT motion single axis. Field measurements (using perhaps triaxial accelerometers) show significant differences in vibrations along different axes of land, sea and air vehicles, and thus multiple shakers are needed.

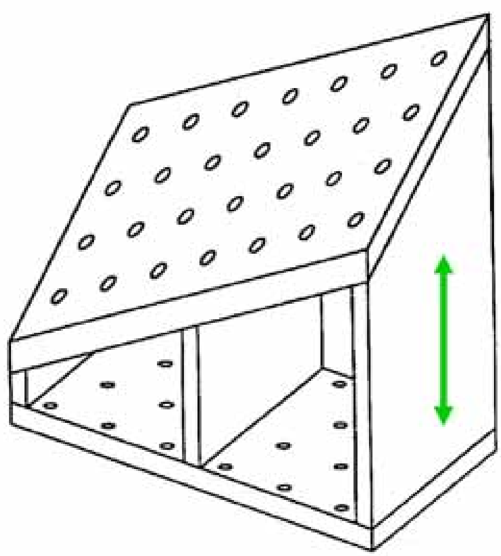

Figure 6 - Fixture for tilting a DUT relative to shaker motion. The result is still single-axis motion, says the author.

Figure 7 - Contrivance for tilting an ED shaker, thus allowing the upright DUT to move along a tilted single axis.

The Army Research Lab at Adelphi, MD had a problem. A field failure, clearly vibration induced, could not be replicated by sequential axis shaking. Somehow the lab obtained two additional shakers and placed them as in Figure 8. Now the field failure could be replicated. This experience has been replicated at Adelphi and elsewhere. The author added three bidirectional arrows to the illustration.

Figure 8 - This pioneer grouping of three ED shakers suggests the complications of on-the-job assembling of three ED shakers, permitting simultaneous multiaxis shaking without damage to any of the shakers.

Another simultaneous multiaxis three-ED shaker installation is shown in Figure 9. Spherical hydrostatic bearings (the vertical bearings cannot be seen) permit simultaneous multiaxis shaking. The author added the three bidirectional arrows.

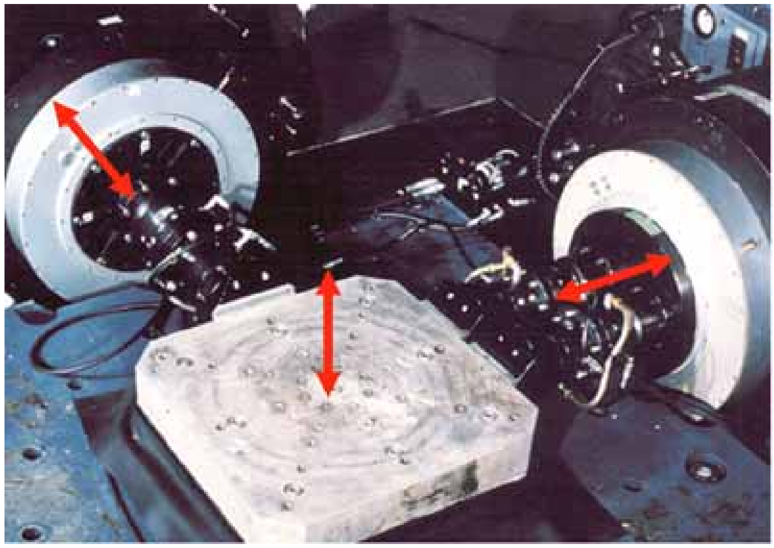

Figure 9 - An interesting variation of assembling three existing ED shakers into simultaneous multiaxis shaking.
courtesy Team Corp. and White Sands Proving Ground

The US Navy has only one such installation, at Naval Underwater Warfare Center, Keyport, WA, Figure 10. The author added the three bidirectional arrows to Figure 10. Painting out the background has made the shakers more visible.

Figure 10 - Three on-site-assembled ED shakers for multiaxis testing of airborne torpedoes.
courtesy Naval Underwater Warfare Center, Keyport, WA

The US Air Force, near Hill AFB in Utah, on-site assembled eight ED shakers, as suggested by Figure 11. This system permits six motions, possibly better than the three motions possible with Figures 1, 8, 9 and 10.

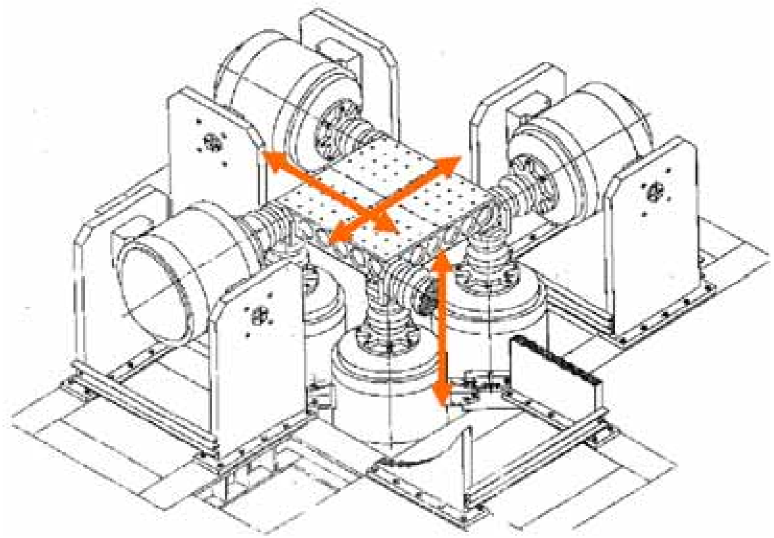

Figure 11 - Eight on-site-assembled ED shakers. *courtesy USAF and Boeing*

Factory-assembled three shaker systems

Much engineering, fabrication and labor is involved in on-site assembling multiple shakers, so Spectrum Technologies of Redford, Michigan, a commercial testing laboratory, invested in the Japanese system shown in Figures 12 and 13. Videos are available at www.www.imv.co.jp/pr/movie/3axis.php. Several Japanese manufacturers build comparable systems, said to be widely used by the Japanese automobile industry.

Figure 12 - The motions of three ED shakers are combined into multiaxis shaking.

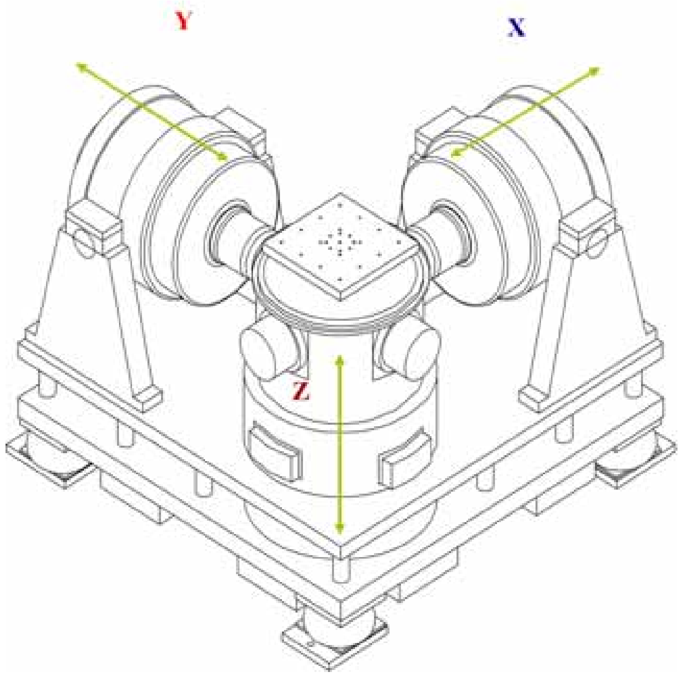

Figure 13 illustrates IMV's method for factory combining three axial motions into one multiaxis motion.
courtesy IMV

Not to be outdone, a Chinese shaker firm has also factory combined three ED shakers, as shown by Figure 14. A video is available at www.dynsolusa.com

Figure 14 - Simultaneous three axis shaking is possible with this shaker system. *courtesy Suzhu Dongling*

Conclusion
This author is concerned that none of the US nor European manufacturers of ED shakers has offered systems for simultaneous multiaxis shaking. And that procurement agencies for military hardware are not requiring the more effective simultaneous multiaxis vibration testing per Test Method 527 of October 2008 MIL-STD-810G.