Sandia's new vibration table promises different ways of testing

July 22 2015

Sandia National Laboratories six-degrees-of-freedom vibration machine research team member Kevin Cross, second from right, adjusts accelerometer cables on a block head test item as, from left, Davinia Rizzo, David Smallwood and Norman Hunter watch. The team is working with a new type of large vibration machine capable of shaking test items in multiple directions simultaneously. The block head is a dynamically active structure designed to challenge the team's ability to control a complex system. Credit: Randy Montoya

It took decades for technology to catch up with the math David Smallwood worked out to control vibration table shakers.

Smallwood, a retired Sandia National Laboratories researcher who consults at the labs, knew that shaking in all directions at once was the key to realistic parts testing. Now Sandia is putting the algorithms he developed more than 30 years ago to the test by shaking up nuclear weapon components.

Vibration machines are crucial to test the forces that make things fall apart in the bumpy real world, from small components to complete systems like airplanes or nuclear weapons. The machines are important to the aerospace and automotive industries, and have been in use since their invention in Germany in the late 1920s.

Large, high-frequency vibration machines that shake things in several directions simultaneously are relatively new. Smallwood's algorithms made them possible, along with developments in digital controls, sophisticated sensors, faster computers with more memory and better mechanical designs.

The standard vibration machine has a single axis that shakes things in one direction at a time. But parts sometimes fail when the real world bounces them from multiple directions: east-west, north-south, up-down and rotations along each of those axes, what's known as six degrees of freedom or 6DOF.

"If you tested it in each direction separately, you could get a totally different kind of failure," said Sandia systems engineer Davinia Rizzo, part of a team working on test specifications for a large high-frequency 6DOF vibration machine installed at Sandia last year, one of only two in the U.S.

Think of 6DOF and single-axis in the context of the pat-your-head, rub-your-stomach exercise for kids. They can all pat their heads or rub their stomachs separately. "But when you combine them, you discover an undetected failure—they can't do one or the other or the timing is off or they rub their head and pat their stomach," Rizzo said. "It's the same with single-axis and 6DOF. You move in one direction and the test unit appears fine. You move in the other and it appears fine. But when you move all directions at once, you discover an issue. We've demonstrated this behavior in the lab."

6DOF could revolutionize testing

Sandia wants to use 6DOF to qualify weapons components and revolutionize the way it does mechanical testing. Better tests could discover currently unknown paths to failure and reduce test time and cost.

"We're mimicking rides on airplanes, [on] rockets or in the back of a truck to ensure components or systems that we're testing are going to survive their environment before we fly them," said Kevin Cross, who's in charge of Sandia's vibration lab. "It's one of our tools to prove reliability standards that we have to meet for our components."

Smallwood, who started doing vibration testing five decades ago at White Sands Missile Range as a New Mexico State University undergraduate, said researchers recognized long ago that single axis vibration testing wasn't enough. "It did not represent the real world," said Smallwood, who consults with the 6DOF team.

Multi-axis shaking was the goal from the earliest days of testing. Norman Hunter, another consultant to the team, worked on Sandia's pioneering efforts in the late 1960s and early 1970s to run two shakers concurrently using analog controls.

That didn't work at higher frequencies. "Things kind of fell apart," Smallwood said. "I used to joke that Norm would sit there with his hand on the abort button so when the system went unstable he could stop it."

Smallwood developed breakthrough algorithms

Sandia researchers began exploring early versions of digital controllers. In 1978, Smallwood developed algorithms outlining digital control of vibration on multiple shakers, the first publication of the math needed to do that. His concept remains the foundation for today's multi-axis vibration controllers.

The breakthrough came when he figured out how to derive correlated or partially correlated multiple signals in real time. "That's what we had to do for a control system for a shaker," Smallwood said. "You can't put something out, wait to do some calculations and then put something else out. The system insists that you have continuous output."

Sandia built a system in the early 1980s to drive two digitally controlled shakers. It worked, but wasn't practical because computers of the time were too slow.

Seattle-based Team Corp. came up with a 6DOF shaker design about a decade ago. "I looked at it and said, 'That might actually work,'" Smallwood recalled. The company built a small 6DOF machine as a demonstration and research tool. After getting feedback, it developed its large 6DOF machine, capable of testing items up to 50 pounds.

The machine has 12 barrel-like electrodynamic shakers, four on each side for the horizontal X and Y axes and four underneath for the Z, or vertical, axis. Using the various shakers together in different configurations achieves rotations around each axis. The shakers, which exert 4,000 pounds of force per axis, drive a 30- by 30- by 14-inch rectangular block in the center where a test piece sits.

The machine is meant for component- or subsystem-level tests. It doesn't have enough force for very large items, and augments rather than replaces Sandia's larger single-axis shakers. Single-axis machines do separate tests at individual axes and experimentalists combine those to arrive at multiple-direction results.

New technology brings new challenges

The very newness of 6DOF poses challenges. "There are tons of questions about how to use 6DOF in our testing philosophy, what to use for specifications and how to control 6DOF machines," Rizzo said. She's part of the team studying minimum drive, an approach Smallwood developed.

"The idea behind minimum drive is that nature likes minimum-energy solutions," Smallwood said. The team wants to find the minimum inputs needed to accelerate the system to required levels at various frequencies. "The assumption is that this is close to what nature would do," he said. "We are trying to maximize the capability of the shaker system by mimicking nature."

Hunter said the challenge is replicating real-world environments for multiple directions and developing specifications for minimum drive. "I think we also really need to learn a lot about the quirks of controlling these multiple degrees of freedom simultaneously. We're still fairly new at that," said Hunter, who spent decades doing vibration testing at Sandia and Los Alamos national laboratories.

Sandia has performed two experimental 6DOF tests of nuclear weapons components, one for the B61-12 and one for the W88 ALT (alteration) 370, said Laura Jacobs, 6DOF research lead.

"These tests are a much better representation of what happens in the field so we can create better computational models and we can have more confidence in our designs," she said.

The 6DOF system is unlike any other, so it requires different ways of specifying tests—sometimes without all the data needed from the field, Jacobs said. "A big part of preparing for the test is determining what we need, and then how to achieve what we need."

Using computational modeling to help fill gaps

Some field tests haven't been done; others don't capture everything that could happen. The team wants to determine how to run a successful test when they lack complete field test information. Team members have turned to computational modeling to figure out from the existing data what the tests need to achieve, Jacobs said.

Cross said researchers have begun combining field test data from the X, Y and Z axes for simultaneous directional testing. But rotational data doesn't exist, and without it, no one's sure how to design a rotational test, he said.

Still, he said, "we can prove that just doing three axes together is a better representation of a real-world environment, even without the rotations."

The latest international standards for vibration tests list what Rizzo describes as a generic placeholder for multi-axis testing. "At least it recognizes multi-axis testing as an acceptable type of test to do, which is a big breakthrough," she said.

"It's going to be cool to develop this capability and have the research and the math and the evidence behind it to prove how this partners with single-axis testing and takes us to richer understanding," Rizzo said.

Then she laughs. "Until 50 years from now when they come up with new technology and we go through all of this again."

Provided by Sandia National Laboratories