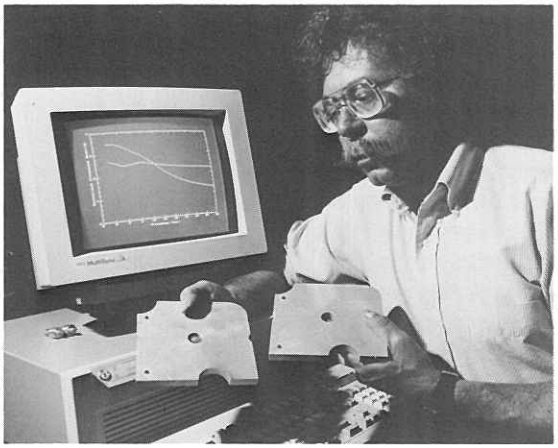
Resonant Ultrasonic Inspection

Inventors: Albert Migliori, Physics Division, and William M. Visscher, Theoretical Division



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The resonant ultrasonic inspection technique is used to find flaws, cracks, and tolerance errors in rigid objects by comparing the acoustic signature of an object with either an earlier signature of the object or the signature of a reference or "good" object. When a flaw is present, the signature appears altered. The computer screen shows two superimposed signatures—one from a good, the other from a flawed test object.

Nondestructive testing, a search for flaws without damaging the object, is essential to American industry. Critical aircraft components, for example, must be inspected regularly for the tiny crack that could grow into the cause of a crash. In one widely used nondestructive inspection method, pulse-echo ultrasonic testing, sound pulses scan the surface of an object to produce echoes. When a scanning pulse hits an internal flaw, the echo changes. But because curved surfaces limit the depth at which flaws can be detected and because a scan width is about 10 millimeters, pulse-echo ultrasound testing is not feasible for large objects or those with complex shapes. Now researchers at Los Alamos National Laboratory have developed a fast, accurate, inexpensive test for finding flaws in rigid objects of any size or shape. The inventors expect their test—Resonant Ultrasonic Inspection—to have a revolutionary impact on industry. Recognizing the importance of the test, *Research and Development Magazine* selected Resonant Ultrasonic Inspection for a 1991 R&D 100 Award. The awards are made to the year's one hundred most significant technical innovations. One patent has been issued and two are pending on the technique.

In the new technique, continuous ultrasound fills the entire test object. The object resonates like a bell. A flaw, a crack, or a tolerance error shifts and damps the resonances and can be detected by comparing the object's "fingerprint," a plot derived from the resonances, with a fingerprint obtained from a "good" object. If a good reference fingerprint is unobtainable, a variation of the technique can produce, under proper conditions, a fingerprint that reveals cracks. Any solid object that rings when struck, from the nose wheel of a fighter plane to liquid storage tanks, is a candidate for such testing because, unlike conventional ultrasound testing, the technique is not limited by the object's size or shape. The test is quick, simple, and inexpensive enough to do on production and assembly lines. It could also be done using a portable unit during routine servicing of aircraft, for example, and reliable go/no-go decisions could be made without major disassembly.

The equipment needed for the test includes only a lap-top computer and software; two commercially available printed circuit boards; two transducers, 1.5 to 15 millimeters in diameter, depending on the test object's size; and an electronics package that is smaller than a cellular phone. Very little skill by the operator is required. The operator attaches a pair of simple, low-power, broadband ultrasonic transducers anywhere on the test object. The transducers run on a few milliwatts of power derived from the computer, an amount of power sufficient to examine objects as massive as 20 tons.

The resonances are generated by slowly sweeping the frequency used to drive one transducer over a range that depends on the object's size. Each resonance produces a peak in the response of the second receiving transducer. Any signal received is the right signal; the operator does not have to fine-tune it. The computer processes the resulting scan to locate these peak frequencies; widths and amplitudes are discarded. Finally, the computer constructs a mode density plot by determining the number of peaks per unit frequency interval. This plot is the object's fingerprint. It represents the object as a whole and is only weakly affected by temperature or transducer type, location, or coupling strength.

The mode density plot is then compared with a plot obtained earlier from the test object or with the plot from a known good object. When no reference plot is available, the operator coats the object with a liquid, such as a volatile solvent or a wax, and then carefully dries it before generating resonances. The cracks retain the liquid, and the resonance patterns reflect the difference in stiffness between the liquid-filled cracks and the rest of the object. Neither version of the test locates the flaw, but either one determines its presence and approximate size. And when the flawed object must be replaced, detecting flaws quickly and inexpensively is more important than locating them precisely.

Resonant Ultrasonic Inspection is a major advance in nondestructive testing. It is faster, more reliable, and less than half as expensive as conventional testing on certain components. Also, it can be used on objects that are impossible to inspect with other nondestructive tests. Because resonances are measured, the flaw or error does not need to be near or on the line of sight of either transducer, as it must be for other ultrasonic tests. An object that is complex, large, or difficult to access can be scanned for flaws by a single transducer setup, which need not be on a flat surface or well-coupled to the object. The scanning can be done in seconds to minutes, much less than the time it takes to scan the entire surface area of an object with other methods.

Applications

The advantages of the technique mean that real-time, go/no-go testing during normal maintenance or on production and assembly lines is now possible for whole classes of objects that cannot be tested with conventional ultrasound methods. For high-precision parts the new test could detect tolerance errors of 50 parts per million in a controlled temperature environment. For example, errors of 0.01 millimeter could be detected anywhere in a new 30-centimeter-long turbine rotor blade. The test can also detect internal flaws in highly curved objects like the internal parts of hydraulic dampers. Critical aircraft parts could be inspected between flights. Such an application is under consideration by the United States Air Force Logistics Command, which would use the technique to create life histories of the landing gears and wheels of its jets. These histories would be created using a 20-second resonant ultrasonic scan to take initial fingerprints when the parts came off the assembly line. When the jets were disassembled for maintenance, new fingerprints would be taken and compared with the first ones. Parts would be replaced when comparisons indicated cracks or aging. The same procedure could be used by commercial airlines to increase the safety of their fleets.

Resonant ultrasonic testing is also being considered for use in treaty verification. Soviet and American inspectors could use the technique for nonintrusive field inspections of missiles to determine whether they are what they are purported to be. The inspection could be done without the use of x-rays or probes that might reveal secret design features. The inventors predict that their technique is scaleable to detecting flaws even in battleships or bridges. But what may be among the most important applications of Resonant Ultrasonic Inspection are these two: the inexpensive tool it gives to industry for correcting flaws on the production line and its potential to prevent an airline crash.

Inventor Albert Migliori's interest in resonant ultrasound grew out of his work at the Laboratory on ultrasound in metals and minerals and ultrasound and microwave properties of high-temperature superconductors. He has used resonant ultrasound in both basic research and programmatic work at Los Alamos. In the latter work he was a member of a team that won a 1989 Distinguished Performance award for the development of new methods for fingerprinting objects using resonance spectra. He also contributed to basic research that produced new information on high-temperature superconductors and other materials.

Migliori earned the B.S in physics at Carnegie-Mellon University and the M.S. and Ph.D. in physics at the University of Illinois. He came to the Laboratory in 1973 as the holder of a two-year Director's Office Post-Doctoral Fellowship. He remained at Los Alamos for another year as the winner of a National Science Foundation Energy Related Postdoctoral Fellowship. In 1976, he became a staff member in the Condensed Matter and Thermal Physics Group, where he has been since. He is the author of 51 publications and three book chapters and has been awarded 14 patents.

William M. Visscher has been a staff member in the Theoretical Division at Los Alamos since 1956.

Visscher (left) and Migliori prepare to test an aircraft wheel.

His research interests have included nuclear physics, the Mossbauer effect, lattice dynamics, and accelerator theory. In the late 1970s he became interested in non-destructive evaluation and developed theories for the scattering of ultrasonic waves from defects. He developed new procedures for calculating the frequencies of ultrasonic resonances and provided other theoretical backup for the invention of the technique of Resonant Ultrasonic Inspection.

Before coming to Los Alamos, Visscher earned a B.A. in physics at the University of Minnesota and a Ph.D. in physics at Cornell University and was a research associate and teacher at the University of Maryland.

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