Ultrasonic testing is based on the transmission of ultrahigh-frequency sound waves through a material. Travis M. Nelson* and Dr. Ronald W. Smith** Materials Resources International, Lansdale, Pennsylvania

Scanning acoustic microscopy (SAM) utilizes advanced imaging software and precision motors to transform ultrasonic testing data into easily understandable, high-resolution images of discontinuities in the material being scanned. Ultrasonic testing is based on the transmission of ultrahigh-frequency sound waves through a material. The system measures and interprets the amplitudes and locations of any reflected sound to produce “A-Scan” data, as shown in Fig. 1. “C-Scan” testing maps these A-Scan data to correspond to the areas being tested. The C-Scan imaging technology has been used for decades, but recent advances in software and hardware have increased the capabilities of C-Scan testing to the point that it can appropriately be called “acoustic microscopy.” However, this microscope has the ability to see inside a part, not just on the surface.

This article explains how SAM works, then describes how it finds flaws in brazed joints and in electronic packaging.

How ultrasonic imaging works
Ultrasonic imaging, or any type of ultrasonic testing, consists of two methods.

• **Pulse-echo** methods, a transducer emits a pulse of ultrasonic energy and reads the reflection itself. This allows for inspection from one side of a part and permits evaluation of the depth of the reflection, in addition to the area. Pulse-echo C-Scan generally produces images in which the “good” areas are dark, and the flaw indications show up in shades of gray and white, or as a designated color palette.

• **Through-transmission** methods have two different transducers, one to send and the other to receive the ultrasonic pulses. This produces an image much like that of an X-ray. Well-bonded regions transmit sound, and appear white. Regions that are not bonded well enough to allow sound to pass through appear dark in the image. This allows for a simple “Go/No-Go” test result and for faster inspection of materials.

From traditional UT to SAM
Scanning acoustic microscopy is a recent advance in ultrasonic C-Scanning, and has evolved due to advances in high-precision motion guidance electronics, data acquisition speed, and software. Together, these technologies produce C-Scan images with resolution of about five microns. SAM is based on the fact that sound travels at a constant speed through a given material. A mismatch in acoustic impedance between two materials coupled together causes the sound to reflect, and the amplitude of that reflection corresponds to the magnitude of the acoustic impedance mismatch.

This means that brazed, soldered, diffusion-bonded, welded, or epoxy-joined materials exhibit a reflection at the bond line. However, an even more significant reflection appears in discontinuity areas such as cracks, porosity, voids, or other discontinuities, because of the local acoustic impedance mismatch.

Ultrasonic C-Scan takes these principles a step further. A computer-controlled scanning platform, as shown in Fig. 2, takes millions of A-scan data points and digitizes the amplitudes of the sound received by the acoustic transducer. The platform maps them relative to their precise locations on the part via computer-based tomog-
raphy. The data are then plotted as gray scale or color to indicate the amplitude of reflected sound. The result is an image of the joint interface, or of a particular cross sectional layer in the part. The quality and ability of any such image is determined by a number of factors. The size, type, and frequency of the transducer are crucial. A 25 mm (1 in.) diameter, straight-beam, 5 MHz transducer does not provide the same sensitivity or resolution as a 6 mm (0.25 in.) diameter, focused, 50 MHz transducer. Furthermore, the higher the frequency and the shorter the focus of the transducer, the greater the sensitivity of the ultrasonic A-scan data, and therefore the greater the resolution of the image produced.

For some acoustic microscope systems, such as the Matec system at MRI, transducers with frequencies as high as 250 MHz are appropriate. However, the ability to take advantage of such high-frequency transducers effectively depends on the accuracy and repeatability of the motion system, which includes both the software and the hardware that moves the transducer around the immersion tank.

A transducer that can detect a ten-micron flaw coupled with a motion system that is only accurate within 10 mm does not offer the repeatability of an acoustic microscope with a higher-precision motion guidance system. Today’s best acoustic microscopes have magnetically driven linear servomotors that guide the search tube and its transducer, allowing for control, accuracy, and repeatability within a few microns.

Case study #1: complex braze joints

One situation in which SAM finds great utility is the nondestructive inspection of parts with irregular geometries, such as parts with brazed surfaces inside an orifice, or obstructed by an overhanging portion of the part, especially if the part does not have a uniform thickness behind the braze joint(s).

An example of such a part is shown in Fig. 3. This is a steel brake caliper that has a nickel alloy wear pad nickel-brazed to the flat, essentially rectangular horizontal surface facing up. A nickel alloy pad is also brazed to the semicircular, flat surface above it. Figure 4 shows this semicircular surface after the brazing operation. Several parts like this one were fabricated and inspected throughout the qualification and production processes.

The specification that governs the brazing process for these parts is AWS Specification for Furnace Brazing, AWS C3.6. It requires that the braze joints be nondestructively inspected with a method that produces an image of the joint either by ultrasonics or by X-ray. However, the surfaces behind these braze joints prevented X-ray inspection from being a viable option. Therefore, a SAM technique was developed in which a right-angle search-tube and an acoustic mirror were attached to the transducer to properly situate the transducer for the inspection. Each batch of brazed parts could then be nondestructively inspected per the AWS requirements, including reporting the percentage of adequately bonded area, and the sizes and locations of any discontinuities.

The state-of-the-art analytical software generated an image of the braze joint, as shown in Fig. 5. In addition, by comparing it to a standard with known defects, the image was analyzed for the percentage of bonded area and the sizes and locations of any discontinuities. Figure 5 illustrates
the localized white area where the acoustic amplitude was high, indicating a lack of bond. These data could then be easily recorded in a spreadsheet program and evaluated against the requirements of AWS C3.6. This helped the customer to refine the processes required to produce the necessary quality in braze joining, as well as to provide quantitative test results without destroying any parts in testing.

Case study #2: electronics packaging

Another area in which the SAM has proven to be useful is the electronics packaging industry. The need for quality control in flip chips, integrated circuits, MEMS, and optoelectronics, has driven acoustic microscope providers to continually raise the bar for both image resolution and scanning speed.

An example of such a device is shown in Fig. 6, which is a cross-sectional schematic of a basic electronic chip package. In this case, the silicon computer chip is bonded with epoxy or solder to a heat spreader made of a material such as copper. The quality of such joints is crucial to assure that computer chips can be effectively cooled during operation. In addition, metal leads connect the chip to a lead frame, which holds the chip package onto the circuit board. Plastic encapsulates the entire package, and must be well adhered to both the top of the chip and the bottom of the heat spreader. Each of these layers, as well as other layers in different types of packages, can be resolved and evaluated by SAM.

Electronic and optoelectronic components can be tested in several ways, but few of the available methods are nondestructive in nature. X-rays can do the job, but this involves radiation, an additional concern for the customer and the testing laboratory. The chips can be tested by simulating service conditions on a standardized circuit board, but this method only indicates whether or not the chip packages are currently operational, without giving any indication of whether they will be able to withstand thermal cycling in service. Even fatigue life tests that simulate thermal cycles, only separate the good chips from the bad, without providing information as to the location or root cause of any noted failures.

SAM technology can provide not only an assessment of each individual chip’s status, but also a location, depth, and type of any detected discontinuity, without any radiation concerns and without chip package damage. Individual loose chips, packages attached to circuit boards, and even entire trays of chips can be examined in the condition in which they arrive from the manufacturer.

In one case, several chip packages for military computer systems were analyzed, and some of the results are shown in Fig. 7. Testing parameters and procedures were developed, and chip packages with configurations similar to that shown in Fig. 6 were evaluated.

In this test, a 15 MHz transducer with a 6 mm spherical focus was positioned at the surface of the electronic package, which was submerged in water for effective sound coupling. Figure 7 shows a significant localized change in acoustic impedance, leading to strong acoustic reflections that are picked up and plotted as “red” by the SAM unit.

These chips were failing destructive tests in the Quality Control laboratory of the company using them in production of the circuit boards. SAM was able to find defective chips in every batch of chips tested, as they arrived from the supplier, before any assembly or testing.

Furthermore, SAM was able to characterize the nature of the defects in each chip package. Some exhibited delamination of the packaging material from the top of the chip. Others displayed voids in the under-fill holding the chip to the heat spreader.
spreader, or delamination between the heat spreader and the bottom of the chip package. The red area on the top-left chip in Fig. 7 represents die-top delamination, an area that covers roughly one-twentieth of a square centimeter. Precision X-ray could have detected the presence of such a defect, but not the layer of the chip package in which it was located.

Successfully finding a means to nondestructively examine these chip packages prior to assembly into their respective circuit boards eliminated the need to destructively fatigue life-test the packages after assembly, saving money for the customer both in manufacturing and in quality control.

Future technology

Ultrasonic C-Scanning has seen recent advances in the technology that governs its capabilities. These include improvements in motion control, high frequency transducers, high speed data acquisition software, and imaging software.

Where once a screw-driven motor controlled the search tube and transducer, now magnetic servomotors govern this motion, permitting both high speed scanning and precision location and analysis of discontinuities, down to the range of a few microns. Advances in composite technology have allowed for transducers with frequencies of 250 MHz or higher, which have empirically exhibited the sensitivity to detect defects as small as five microns in diameter and to detect gaps as thin as one-tenth of a micron. Software and firmware advances permit higher-speed scanning without sacrificing sensitivity or resolution, thereby saving money by saving time when numerous parts or large areas must be examined.

In addition, the memory required to store files with very precisely incremented layers and/or multiple areas is now possible with today’s data acquisition and storage software and hardware. The imaging capability now possible by scanning acoustic microscopy, whether imaging tiny solder bumps, large braze layers, or something in between, can bring manufacturers, technicians, and nondestructive testing personnel improved images of internal structure in materials with greater understanding in interpretation.

For more information: Travis M. Nelson, Materials Resources International, Lansdale, PA 19446; tel: 215/631-7111; fax: 215/631-7115; email: tnelson@materialsresources.com; Website: www.materialsresources.com/sam/sam.htm