Sound proving techniques

IMPROVEMENTS IN ULTRASONIC INSPECTION OF PARTS CAN HELP TOWARD REDUCING THE COST OF THE DEVELOPMENT PROCESS

"The couplant used in automated testing is usually water; a gel can be used for manual inspections"

BY CHRIS GARTSIDE

The increasing use of composite materials in aerospace structures brings with it the need for more cost-effective non-destructive testing (NDT) equipment and procedures. The application of advanced manufacturing processes using exotic materials is another factor that places demands on NDT equipment suppliers. Aerospace manufacturers constantly strive to reduce the cost of testing, and the inspection time is a crucial factor. Test equipment suppliers have to continuously refine their equipment to help manufacturers reach this goal.

One of the principal NDT methods is ultrasonic testing using frequencies of 0.5-25MHz. Pulses of ultrasound are transmitted into the material under test, and the reflected or transmitted signals are analyzed to provide information on the material structure. Although manual testing is still widely used, an increasing number of inspections are carried out using automated systems that generate acoustic images, known as C-scans and B-scans. These display plan-view and cross-sectional images respectively.

There is a wide range of features in aerospace materials and structures that can be imaged in this way. For wrought metals such as plates and forgings this includes porosity, inclusion, and lamination defects when they exceed a specified size. In welded assemblies the problem features are likely to be lack of fusion, porosity, and cracks. As far as composite structures are concerned, producers need to detect bonding defects, delaminations, and porosity as well as the presence of foreign materials in the lay-up. Because of their multiple layer structure, metallic parts fabricated by SPFDB processes (superplastic forming and diffusion bonding) are inspected for similar defects.

As ultrasound at the required frequencies cannot be transmitted efficiently through air, a liquid 'couplant' is used between the probe that generates the ultrasound and the part under test. The couplant used in automated testing is usually water; a gel can be used for manual inspections.

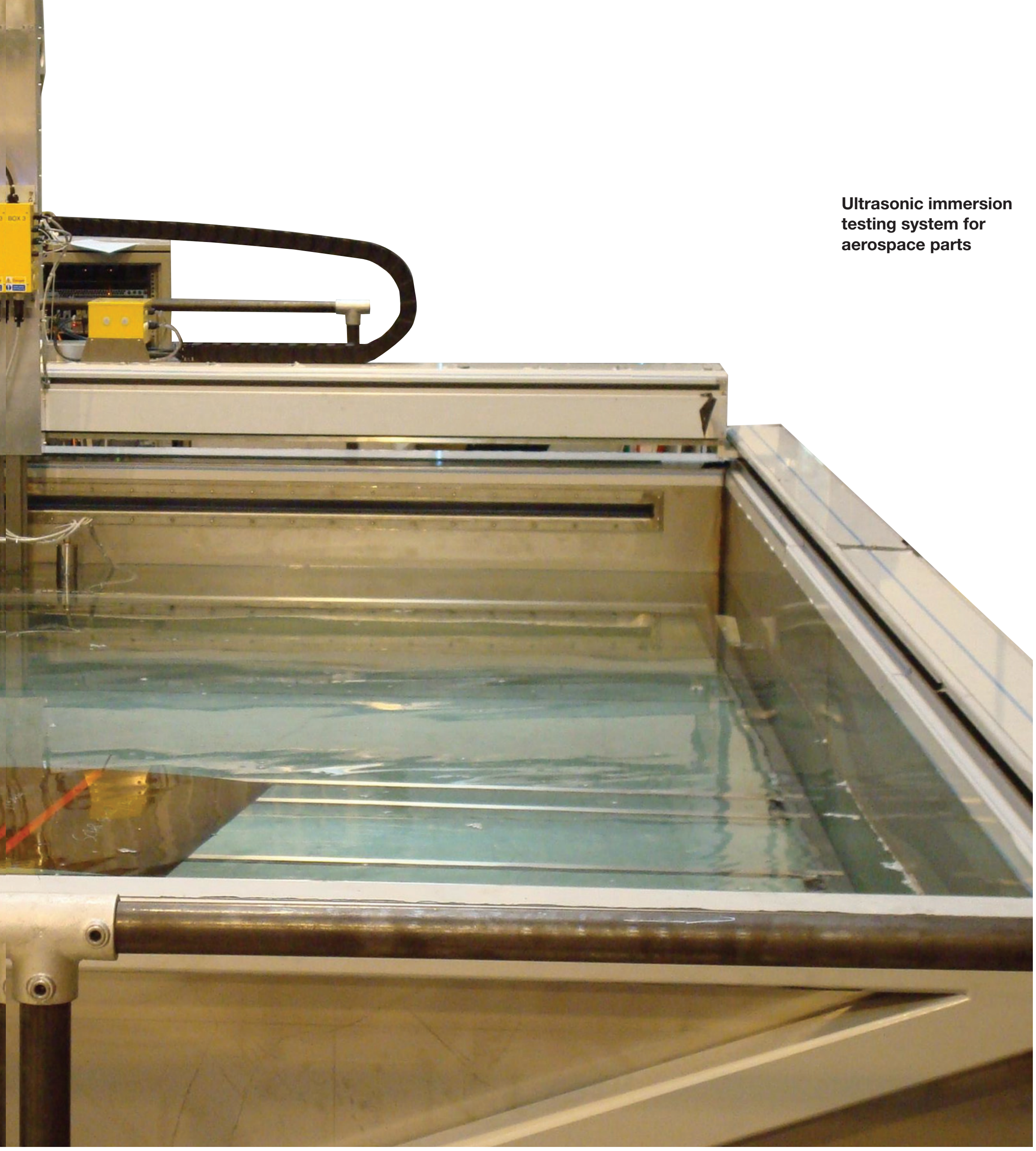
CHRIS GARTSIDE

Inspection techniques

Machines designed for automated testing use one or more of the three main techniques for coupling the sound into the test material. These are contact, immersion, and water jet (squirter) inspection. With contact testing, as the name implies, the inspection probe is in contact with the product being tested. This has the advantage that mechanical followers can be used to test shaped products, but the inspection speed is usually limited and there are other technical issues that prevent wider application.

In most cases immersion or squirter techniques are used, where the tested parts are completely immersed in water or where the sound is transmitted through water jets. Immersion methods usually involve inspection from one side only, using the pulse-echo technique, in which the same probe is used as transmitter and receiver. In recent immersion systems installed by Ultrasonic Sciences Ltd (USL), the productivity of the system is improved by the ability to operate in two different modes, dependent on the requirements of the inspection and the shape of the part. In the first mode, complex-shaped parts are scanned using a single probe. This is relatively slow, with typical linear speeds of 500mm/sec, scanning in a raster fashion at 1mm pitch – this is roughly equivalent to a coverage of $2m^2$ per hour. For much higher throughput the system can operate in the second mode. This uses an array probe typically 100mm wide, with a combination of electronic scanning across the array and mechanical motion. This is capable of achieving a throughput of more than $1m^2$ per minute on flat and single-curved products, which is a dramatic increase in productivity compared with a single probe.

With this system a probe array containing



Ultrasonic immersion testing system for aerospace parts

up to 128 individual elements is used. Groups of these elements are fired sequentially, with the selected group being indexed across the array in small increments. This occurs at very high speeds, typically up to 20,000 times per second, which means the complete array can be electronically scanned several hundred times per second as the array moves mechanically to cover the entire area of the part. Each individual sound beam, or 'focal law', can be controlled so that it interrogates a small area of the test material, producing a very detailed image.

With squirter methods the sound is transmitted by a probe through a water jet on one side and received by a second probe on the opposite side. During scanning, the angle of both water jets must be accurately controlled and they must also remain coaxial, otherwise the ultrasound signals are lost. This places severe demands on the control of the mechanical systems, especially when scanning complex parts with dual curvature. Productivity improvements here are more difficult, but in USL systems scanning speeds have been increased even on complex shapes without compromising the quality of the inspection.

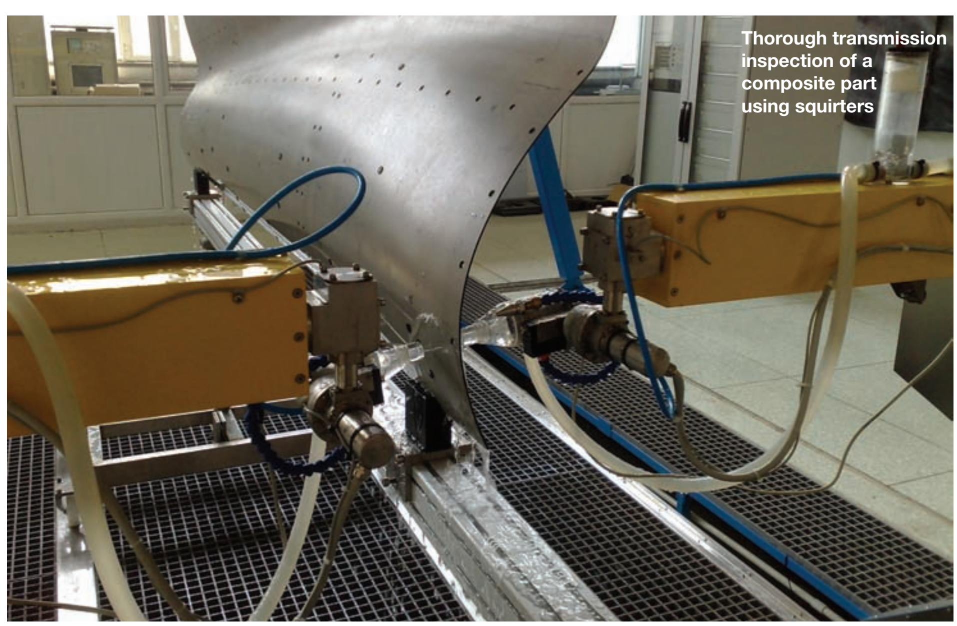
The shape of manufactured composite parts can be very complex in military and commercial aircraft structures. Ultrasonic testing systems need to incorporate multiple mechanical axes in order to scan these complex shapes. Typically systems will have 10 to 12 axes, with all of these simultaneously controlled in order to follow the profile. The illustrations show USL machines with two different configurations: one with horizontal opposed manipulators and the other with vertical manipulators in a gantry or portal style. The choice is governed by the range of shapes to be inspected and also by the test methods specified by the user. Sometimes the squirter and immersion methods are both required; in these cases the vertical system is the preferred option.

CATIA models

For immersion and squirter systems a major potential bottleneck in programming the shape of the parts has been by-passed by generating the complex scan profiles directly from CATIA (computer-aided three-dimensional interactive application) data.

Unfortunately the CATIA model, especially in a composite component, does not always represent the actual shape of the part at the inspection stage. This is partly a result of 'springback' after removal from the molding tool, and also because these parts are not usually self supporting and can easily droop or twist when held at two or three location points. In addition to this, there may be small differences in the location of the part in the testing machine.

Although the sum of the differences may be small, it is enough to affect the validity of an ultrasonic test on a complex-shaped part. USL has developed procedures that automatically measure the true position and shape of the part before the inspection begins. This adjusts the scanning profile in three dimensions, recalculating the instantaneous positions of up to 12 axes so that the probes follow the actual shape rather than the theoretical shape. This procedure avoids the need for rescanning, which in normal circumstances may only become apparent toward the end of



Thorough transmission inspection of a composite part using squirters

Squirter system with 12 axes – vertical gantry type

Large-scale immersion system for plate inspection

"In any ultrasonic test it is crucial to control the angle of the sound beam with respect to the surface"

a lengthy scan.

In testing semi-finished aerospace products it is usually necessary to generate detailed ultrasonic images, so that any problem areas can be visualized. A degree of automated analysis can be applied to these images, but this is limited because of the complexity of structures. It is much easier and quicker for an operator to analyze the images. Homogeneous materials, however, can lend themselves to automated analysis, so that defects are highlighted and the operator merely has to confirm that an indication is a defect and not an artifact. A typical example is in inspection of aerospace aluminum alloy plate, where defects as small as 0.4mm diameter may have to be detected with 100% reliability in material up to 200mm thick.

Ultrasonic squirter system with 10 scanning axes – horizontal type

It is essential to use highly specified ultrasonic instrumentation, with a high signal-to-noise ratio and exceptional immunity to external noise sources. However, this alone is not enough to ensure 100% detection of small defects. This has prompted USL to incorporate special features in systems of this type, which are now in widespread use throughout the world.

Sound control

In any ultrasonic test it is crucial to control the angle of the sound beam with respect to the surface. This is simple if the tested product is perfectly flat, level, and parallel, but this is seldom the case in practice. In fact the variation in surface profile may be random and unpredictable.

In order to achieve a high material throughput in plate inspection, multiple probe assemblies are employed with multiplexing instrumentation. Typically seven to 15 rectangular probes will be used in a staggered formation, covering a band of material between 80 and 150mm wide. As the material is scanned in an immersion tank, the surface position of the plate is measured by all the probes, at the same time as they are being used for defect detection. The measured distance between the probe face and the plate surface, known as the water path, indicates the angle of the surface relative to the probes. This is used to adjust the probe manipulator in real time, so that the inspection angle is maintained at the correct value – usually 90°. This helps ensure that defects are reliably detected over the entire plate surface.

At the end of the scan, possible defect indications are highlighted on the C-scan image. The scanner automatically moves to each one in turn and the operator confirms that the indication is a defect or an artifact, such as a surface mark or air bubble. Because the rectangular probes are designed for defect detection, but not accurate defect sizing, the system uses a circular focused probe for this part of the sequence. In some cases electronically scanned arrays, as described earlier, are used for these plate-testing applications, but the throughput using multiple probe assemblies is generally higher.

NDT is frequently one of the last things to be considered when parts are designed, and this can create difficult problems. Advanced assembly methods such as diffusion bonding, friction welding, and friction stir welding are now being routinely used to produce very complex metal parts that require some form of NDT. This places new demands on test equipment manufacturers and NDT practitioners alike because the complexity can make access very difficult. Similar problems arise in aerospace composite materials as a result of the wider use of processes such as resin transfer molding. These need to be solved without causing manufacturing bottlenecks and productivity issues, so innovative solutions in instrumentation, mechanisms, and software will continue to be required. ∎

CONTACT

Chris Gartside, sales director

Tel: + 44 (0)1252 350550

Email: chris.gartside@ultrasonic-sciences.co.uk

www.ultrasonic-sciences.co.uk