Advanced Inspection Technologies for Energy Infrastructure

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OVERVIEW: Hitachi is working actively to develop advanced inspection technologies to continue to support the energy infrastructure that will underpin society into the future from the perspectives of measures to prevent global warming and ensuring a reliable energy supply. Representative examples of these inspection technologies include phased array ultrasonic testing systems, portable guided wave inspection systems for detecting pipe wall thinning, and eddy current testing systems. All of these technologies are able to conduct highly reliable inspections in a short period of time and they make a major contribution to the safe and efficient operation of power plants and other energy infrastructure.

INTRODUCTION

AS global attention focuses on environmental problems, there is a demand for advanced inspection technologies that can support the energy infrastructure that is one of the keys to achieving both a reduction in CO_2 (carbon dioxide) emissions and a reliable energy supply. Hitachi has long experience in the development of inspection technologies that use ultrasonic, eddy current, and other techniques to support the long-term stable operation of nuclear, thermal, and other power plants in particular, and is also working to apply the technologies it has acquired in general industry.

This article describes three typical examples of these advanced inspection technologies, namely ultrasonic testing, guided wave pipe wall thinning inspection, and eddy current testing, and gives examples of how they are used.

ULTRASONIC TESTING

Phased Array Ultrasonic Testing

Phased array ultrasonic testing is an inspection technique that works by focusing an ultrasonic beam on a target location in the item being inspected by applying pulse voltages with controlled phase to each piezoelectric element in an array probe that contains a number of these elements. A feature of the technique is that the accuracy of flaw size measurement can be improved while also shortening the inspection time by focusing the beam and scanning it under electronic control.

Hitachi has developed and brought to market phased array ultrasonic testing systems that combine small size and advanced functions.

These testing systems incorporate the S-SAFT (sector-scan synthetic aperture focusing technique) signal processing function[1] developed by Hitachi. The S-SAFT function generates test images with better SN (signal-to-noise) ratio and spatial resolution than previous models by combining multiple scan images obtained by mechanical and electronic scanning of the array probe while simultaneously performing sectorial scanning.

Fig. 1 shows an example of using S-SAFT to detect SCC (stress corrosion cracking) in a weld. The

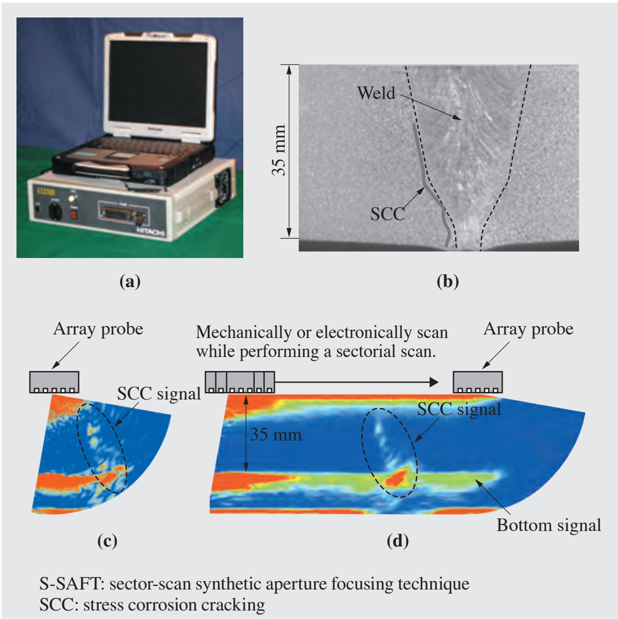


Fig. 1—Phased Array Ultrasonic Testing System and Example Test Images.
The ES3300 phased array ultrasonic testing system (a), SCC in a weld (b), and images of SCC captured using the previous sectorial scan method (c) and using S-SAFT (d) are shown.

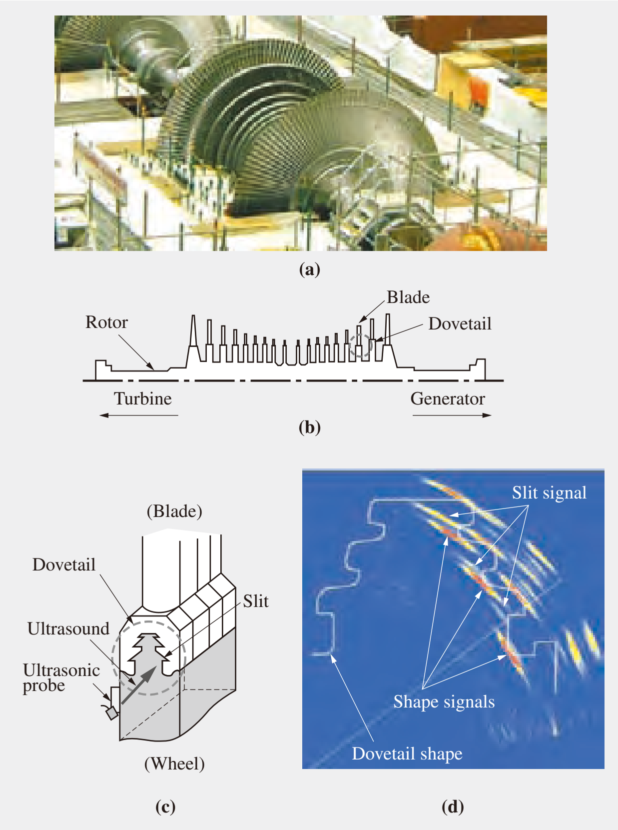
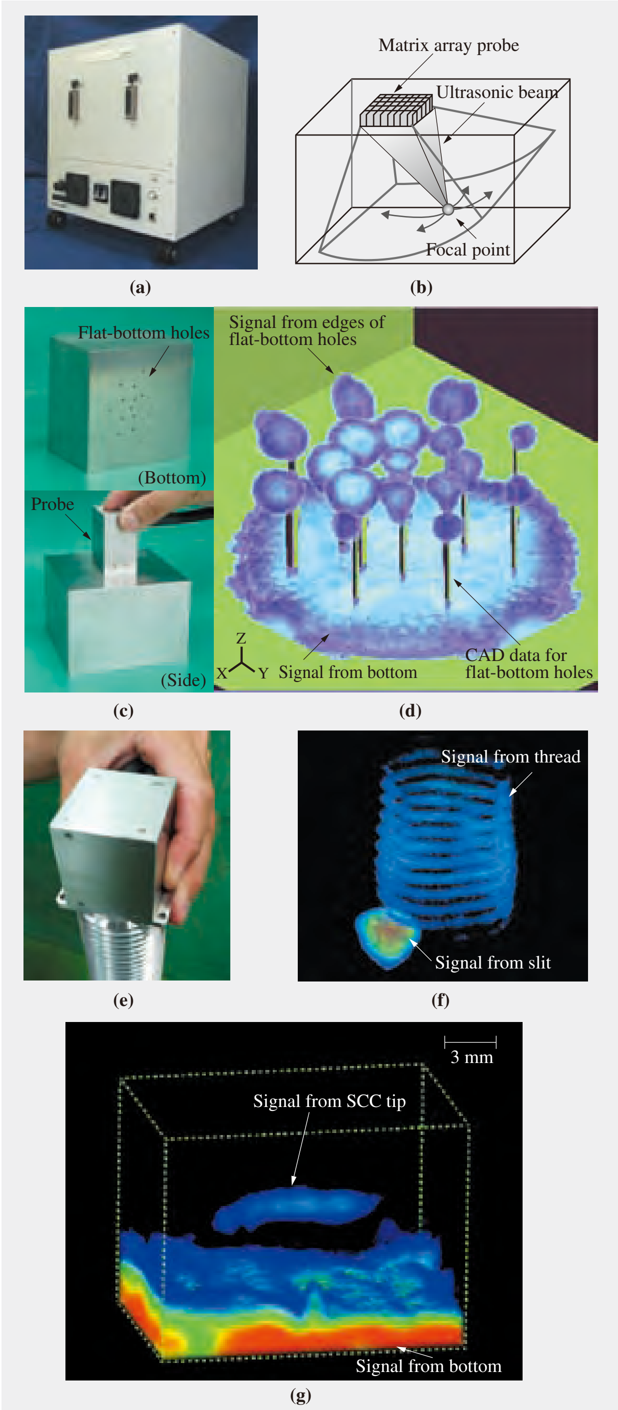


Fig. 2—Ultrasonic Testing of Dovetail Joints in the Low-pressure Rotor Wheel of a Steam Turbine.
Steam turbine (a), axial cross-section of steam turbine rotor (b), dovetail joint and probe position (c), and image of dovetail joint captured by phased array ultrasonic testing (d) are shown.

SCC signal is obtained with greater clarity than using previous methods. Phased array ultrasonic testing has already proved its effectiveness for inspection of critical components in power plants including reactor internal equipment, piping, and steam turbines. Fig. 2 shows an example of phased array ultrasonic testing of a slitted test piece to check the integrity of the dovetail joints (where the blades join to the wheel) in a low-pressure rotor wheel for a steam turbine. Testing is performed by moving the probes on the wheel using a rotating mechanism fitted to the rotor. Image (d) in Fig. 2 clearly shows the signals reflected from the slits (three locations). Because ultrasound can be used to perform an inspection without removing the blades from the wheel, it significantly shortens the time required for the inspection.

3D Phased Array Ultrasonic Testing System

A 3D (three-dimensional) phased array ultrasonic testing system was developed to improve further the speed of inspection(2). The system uses a matrix array probe consisting of a 2D (two-dimensional) array of piezoelectric elements to scan the ultrasonic beam in a 3D pattern under electronic control. The desired 3D



CAD: computer-aided design

Fig. 3—3D Phased Array Ultrasonic Testing System and 3D Test Result Images.
System (a), 3D (three-dimensional) beam scanning (b), stainless steel test piece with flat-bottom holes (c), 3D test image for stainless steel test piece (d), M24 bolt test piece (e), 3D test image of bolt in which a 3-mm slit has been cut to simulate a flaw (f), and 3D test image of SCC (g) are shown.

scan pattern is generated by controlling the phase of the pulse voltages applied to each piezoelectric element. As the scan result can be displayed on a monitor as a 3D image overlaid on CAD (computer-aided design) data, the entire process from data acquisition to results evaluation can be completed efficiently and quickly. Because this method can focus the ultrasonic beam more effectively than before, it can also measure flaw size more accurately (see Fig. 3).

Image (d) in Fig. 3 shows an example test result for a stainless steel test piece machined with a number of flat-bottom holes displayed as an overlay on CAD data. The image clearly shows the reflection signals from the bottom of the test piece and the edges of the flat-bottom holes. Whereas in standard ultrasonic testing a certain degree of expertise and experience is required to distinguish between echo-returns from flaws and from the test item shape, overlaying the result on CAD data makes it easier to interpret the signal. Next, image (f) in Fig. 3 shows an example test result for an M24 bolt test piece cut with a 3-mm deep slit. Because this image can be obtained with the probe, bolt, and other items in fixed positions, a large number of inspections can be conducted in a short period of time. Finally, image (g) shows an example result for SCC. The signal from the tip of the SCC which follows the weld line is clearly evident allowing the spatial extent of the SCC to be estimated. The time taken from data acquisition to 3D display for these examples was only several seconds.

Use of the 3D phased array technology for power plant inspection is already planned and Hitachi subsequently intends to extend use of this technology to general inspection applications.

GUIDED WAVE PIPE WALL THINNING INSPECTION

Guided waves involve the propagation of ultrasonic waves through a long and thin material in the longitudinal direction and Hitachi has developed a portable pipe wall thinning inspection system that uses this phenomenon[3] (see Fig. 4). Although in the past performing an inspection required the removal of all the heat insulation used to clad the pipes, the new system only needs a small region of heat insulation to be removed to screen several tens of meters of pipe for wall thinning at a time. A range of different probes, from 50 A to about 800 A, are available to suit pipe diameters and the system is capable of detecting wall thinning of only 1% of the pipe cross-sectional area in straight piping or small-diameter curved piping.

Also, partially attached probes are currently under development for inspection of large-diameter pipes, tanks, and other structures. Fig. 5 shows the results of tests to confirm the detection accuracy of this partially attached probe using a 500 A pipe with simulated wall thinning. The reflection signal is stronger at the angular position where the simulated wall thinning was applied indicating how the circumferential position of the wall thinning could also be identified in this case. Hitachi is currently collecting field data from power plants and other sites and establishing evaluation methods with the intention of applying this technique in practice in the future.

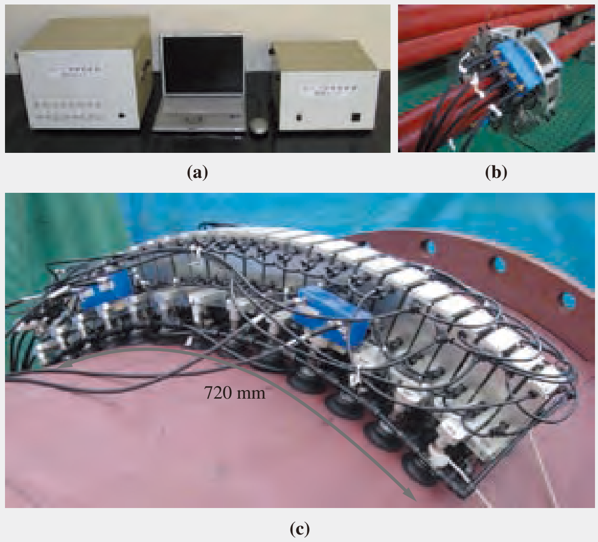


Fig. 4—Portable Guided Wave Inspection System.
Guided wave transceiver unit (a), probe for 50 A pipes (b), and partially attached probe for large-diameter pipes (c) are shown.

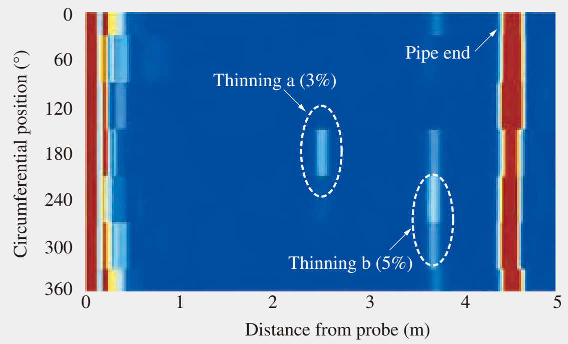


Fig. 5—Example Measurement of 500 A Pipe Using Partially Attached Probe.
Wall thinning was simulated on a pipe with a wall thickness of 9.5 mm and a polyethylene lining on the inner wall by reducing the wall cross-sectional area by 3% at the 180° position (a) and by 5% at the 270° position (b). A series of measurements were performed with the partially attached probe shifted around the circumference by 60° each time.

EDDY CURRENT TESTING

Eddy Current Testing System for Heat Exchanger Tubes

Eddy current testing is a way of detecting flaws near the surface of metal materials. Hitachi has developed a system for using eddy currents to inspect the heat-transfer tubes used in heat exchangers(4) (see Fig. 6). The probe is inserted inside the tube and scanning is performed mechanically. The heat exchanger tubes being inspected are not magnetic and the tube ends are held by “tube sheets” made of ferromagnetic material. Through-holes are machined in these tube sheets and the diameter of the heat exchanger tube inside the holes is expanded so that the tube is held in place by being pressed against the tube sheet, in this article such part is called expanded section of tube.

Diagram (a) in Fig. 6 shows the expanded section of tube. Because fatigue cracks tend to form from the outer circumference at the ends of the expanded section, inspection of this region is particularly necessary. However, the eddy current testing signal is subject to noise from a range of sources including the surrounding tube sheets made of ferromagnetic material and the step in the inner surface of the tube at the ends of the expanded section. This system is able to conduct inspections even of these expanded sections. As shown in diagram (b) of Fig. 6, the probe has a unique coil configuration that passes an eddy current along the tube in the longitudinal direction and measures the eddy current in the circumferential direction. Noise is reduced by using two different excitation frequencies. The graph (c) in Fig. 6 shows the signals measured for a sample in which an artificial crack reaching 50% of the way into the tube wall was formed in the outer surface at the position in the expanded section where the shape changes.

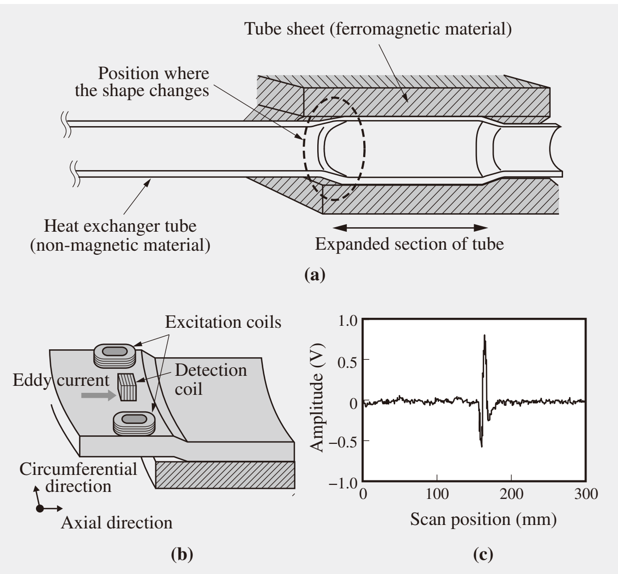


Fig. 6—Eddy Current Testing System for Inspecting Heat Exchanger Tubes.
Expanded section of heat exchanger tube (a), probe positions (b), and measured signal for a sample in which an artificial crack reaching 50% of the way into the tube wall was formed in the outer surface (c) are shown.

Flexible Eddy Current Testing Probe

Hitachi has also developed a flexible eddy current testing system that embeds multiple coils in a flexible substrate (see Fig. 7). Use of multiple coils expands the measurement range and allows testing to be performed more quickly than with conventional single-coil probes. Because the flexible probe can bend to follow the shape of the surface being inspected, it can be used for curved as well as flat surfaces. A proprietary signal processing technique developed by Hitachi can clearly discriminate between flaw signals and noise(5).

These eddy current testing technologies are already being used to inspect power plants and other general industrial products and Hitachi aims to expand the scope of their use further in the future.

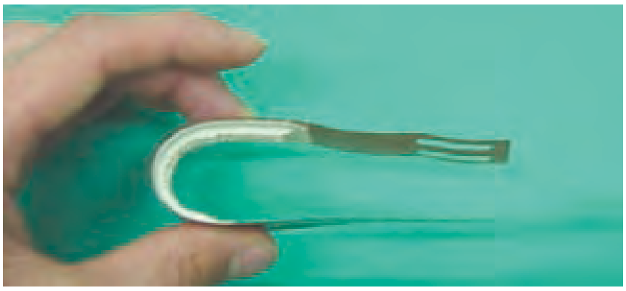


Fig. 7—Flexible Eddy Current Testing Probe.
The flexible eddy current testing probe can be bent to follow curved surfaces as shown here.

CONCLUSIONS

This article has described three typical examples of advanced inspection technologies, namely ultrasonic testing, guided wave pipe wall thinning inspection, and eddy current testing, and given examples of how they are used.

The issue of global warming has been raised as a critical problem of global scale in recent years and what to do about it has become one of the greatest issues that transcend national boundaries. The efficient and safe operation of power plants and other parts of the energy infrastructure is one of the keys to achieving both a reduction in CO_2 emissions and a reliable energy supply and Hitachi believes that its advanced inspection technologies can make a major contribution to achieving this objective.

REFERENCES

(1) O. Kikuchi et al., "Development of a Phased Array Ultrasonic Testing System," Proceedings of the 5th Annual Conference of the Japan Society of Maintenology, pp. 310-311 (2008) in Japanese.
(2) S. Kitazawa et al., "Three-dimensional visualisation and evaluation techniques for volumetrically scanned data of ultrasonic phased arrays," Insight **52**, No. 4, pp. 201-205 (2010).
(3) M. Miki et al., "Guided Wave Technique for Detecting Pipe Wall Thinning in Large-diameter Pipes," Proceedings of the 6th Annual Conference of the Japan Society of Maintenology, pp. 561-564 (2009) in Japanese.
(4) S. Narishige et al., "Investigation into Use of Eddy Current Testing to Inspect Expanded Parts of Heat Exchanger Tubes," Proceedings of the 2009 Spring Meeting of The Japanese Society for Non-Destructive Inspection, pp. 201-202 (2009) in Japanese.
(5) A. Nishimizu et al., "Development of Eddy Current Testing System for Components in Reactor Pressure Vessels," Proceedings of the 5th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, San Diego, USA, May 10-12, 2006, pp. 895-901 (2006).

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