

Advanced Inspection Technologies for Nuclear Power Plants

Mitsuru Odakura
 Yutaka Kometani
 Masahiro Koike
 Masahiro Tooma, Dr. Eng.
 Yoshiaki Nagashima, Dr. Eng.

OVERVIEW: As nuclear power plants age, the importance of maintenance increases and there is a need to apply inspection technologies suitable to the importance of each item of equipment. Hitachi has responded to these demands by developing realistic inspection technologies that provide high precision and can adapt to the different shapes and dimensions of nuclear power plant equipment. High-precision inspection technologies developed by Hitachi include small and easily portable ultrasonic testing instruments with advanced functions and ultrasonic testing instruments able to display crack shapes in three dimensions. In the field of realistic inspection technologies, Hitachi has been working on developments to expand significantly the scope of application of guided wave technology which can be used to perform screening inspections rapidly over a wide area to check for wall thinning in piping. The company has also been working on inspection equipment that is effective at reducing the volume of attendant tasks. Hitachi has established the NDE Center as a base for inspection technologies where it conducts training for specialist technicians and skills retention training for inspection staff covering the use of these nondestructive testing technologies.

INTRODUCTION

THE number of aging nuclear power stations in Japan that have been in operation for more than 30 years is increasing and there is a need to apply inspection technologies appropriate to the importance of the equipment being inspected. In response, Hitachi is working on the development of technologies able to perform realistic and high-precision inspection for cracks, wall thinning and other potential defects at the inspection points on nuclear power plant equipment and piping, which come in many different shapes and dimensions (see Fig. 1). Hitachi is also working hard to improve the technical know-how and retain the skills of inspectors for performing these inspections using the latest technology.

This article describes the development of advanced inspection technologies for nuclear power plant equipment such as phased array ultrasonic testing, ROVs (remotely operated vehicles) for inspecting inside the reactor (submersible ROVs), and guided-wave wall-thinning inspection of piping, and the training and other support for nondestructive testing technicians.

PHASED ARRAY ULTRASONIC TESTING

Phased Array Ultrasonic Testing and Signal Processing

Phased array ultrasonic testing is an inspection method that works by focusing the ultrasonic beam on any desired location by applying pulse voltages with controlled phase to a number of piezoelectric elements in the array sensor. To improve the method's usability in the field, Hitachi has developed a new phased array ultrasonic testing instrument that achieves both smaller size and improved test performance with the aim of upgrading it into a more sophisticated device. The instrument has been released on the market by Hitachi Engineering & Services Co., Ltd. (see Fig. 2).

The newly developed phased array ultrasonic testing instrument incorporates an S-SAFT (sector-scan synthetic aperture focusing technique) signal processing function to improve the resolution and S/N (signal-to-noise) ratio of the test image. The S-SAFT signal processing technique mechanically (or electronically) scans the array sensor while performing the sectorial scan to collect multiple test

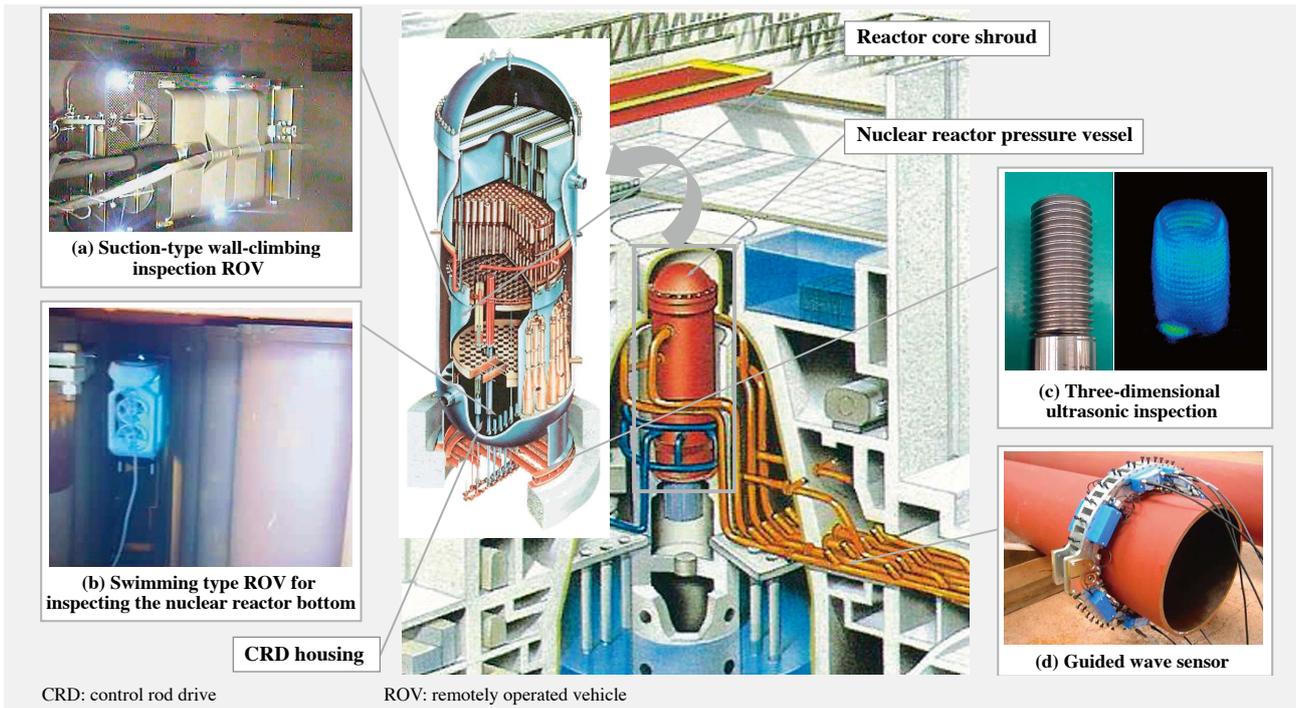


Fig. 1—Advanced Inspection Tools and Diagram of Nuclear Reactor and Reactor Building.

Photographs show a suction-type wall-climbing inspection ROV used for ultrasonic testing and other applications that attaches onto and travels along the reactor core shroud (a), a swimming type ROV for inspecting the nuclear reactor bottom that swims in between the CRD housings at the bottom of the nuclear reactor to perform visual inspections (b), an example three-dimensional display of a bolt thread captured by three-dimensional ultrasonic inspection (c), a guided wave sensor that can perform wall thinning inspection over a wide area of piping (d).

images which are then combined. Not only does the averaging effect improve the S/N ratio, the SAFT also has the effect of improving the resolution (see Fig. 3).

Three-dimensional Phased Array Ultrasonic Testing System

The 3D Focus-UT⁽¹⁾ three-dimensional phased array ultrasonic testing system was developed to speed up inspection and improve the ability to detect

defects (see Fig. 4). This system can perform a three-dimensional scan of the ultrasonic beam while keeping the array sensor fixed, and displaying the test data in three-dimensional form allows the entire test area to be checked at the same time. The features of the three-dimensional phased array ultrasonic testing system are listed below.

(1) Scan condition setting: propagation analysis using three-dimensional ray tracing simulator

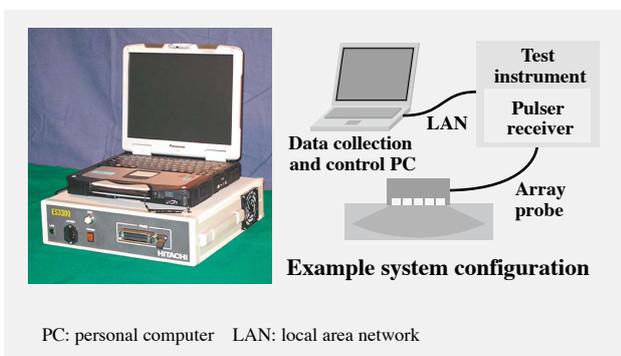


Fig. 2—Phased Array Ultrasonic Testing Instrument. The appearance and configuration of the instrument from Hitachi Engineering & Services Co., Ltd. are shown.

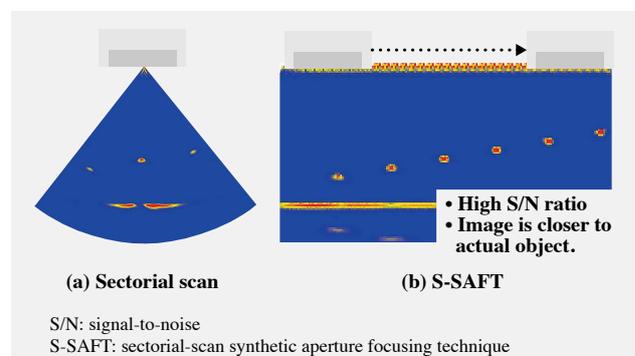


Fig. 3—Example Comparison Between S-SAFT and Previous Method (Sectorial Scan Method).

The image of a test piece with drilled side holes produced by the sectorial scan method (a), and the image produced by S-SAFT (b) are shown.

Analyzes the ultrasound propagation time to each element using a ray tracing simulator from a three-dimensional-CAD (computer-aided design) system.

(2) Data collection: high-speed measurement can send and receive data from 256 elements.

By controlling the delay time to each element in the 256-element matrix array sensor, the point-focused beam is scanned three-dimensionally through the interior of the object being inspected and all the data is collected together.

(3) Image processing: three-dimensional display using high-speed voxel conversion.

Dedicated high-speed voxel conversion and display software developed for the purpose can perform integrated three-dimensional processing.

Fig. 5 shows an example test result for a stainless steel test piece machined with a number of flat-

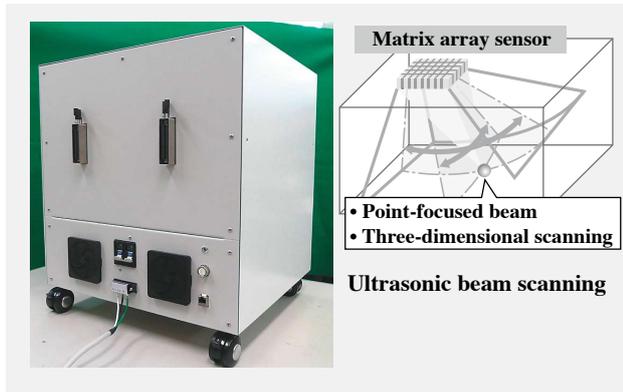


Fig. 4—3D Focus-UT System. The appearance of the three-dimensional ultrasonic testing instrument and a diagram of how ultrasonic beam scanning is performed are shown.

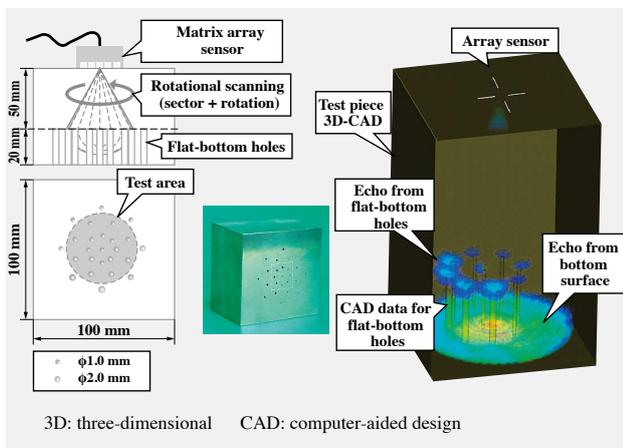


Fig. 5—Example Test Result Display. Test results for a test piece with flat-bottom holes and three-dimensional image displayed as an overlay on CAD data are shown.

bottom holes displayed as an overlay on the CAD data.

ROVS FOR INSPECTING INSIDE REACTOR (SUBMERSIBLE REMOTELY OPERATED VEHICLE)

Undertaking visual testing, eddy current testing, and ultrasonic testing of core internals inside the nuclear reactor is an important part of confirming the integrity of three components. For this purpose, Hitachi developed an ROV⁽²⁾ fitted with a visual testing camera and a newly developed eddy current sensor and ultrasonic sensor to speed up inspection times and help ensure reliability.

Swimming Type ROV for Inspecting Nuclear Reactor Bottom

The housings for the control rod drive mechanism are clustered in a lattice with a spacing of approximately 150 mm at the bottom of boiling

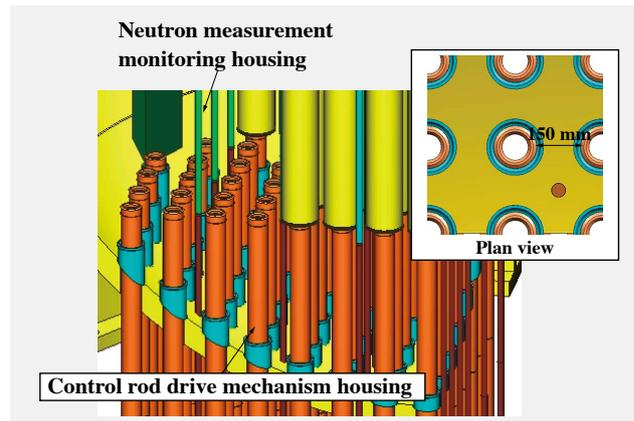


Fig. 6—Layout of Reactor Bottom. The enlarged diagram of the bottom of the nuclear reactor shows the physical arrangement.

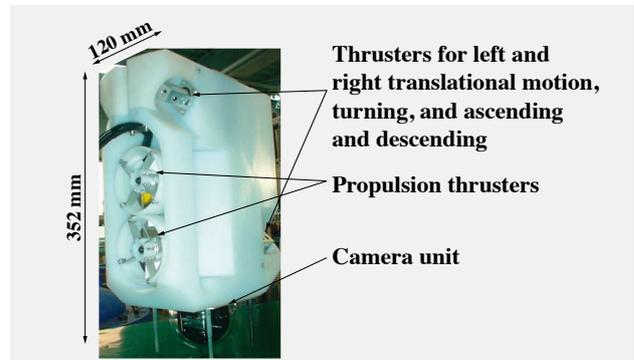


Fig. 7—Appearance of Swimming Type ROV for Inspecting the Nuclear Reactor Bottom. The swimming type submersible ROV for inspecting the nuclear reactor bottom is shown.

water reactors (see Fig. 6). The ROV for inspecting the nuclear reactor bottom is used for operations such as inspecting welds and checking the integrity of structural components in the reactor bottom.

Fig. 7 shows the appearance of the ROV developed by Hitachi. The ROV has a box-like shape with a width of 120 mm to allow it to pass between the structural components in the reactor bottom. The vehicle is fitted with a CCD (charge-coupled device) camera for visual testing and navigation and LEDs (light-emitting diodes) for illumination. The CCD camera is able to pan around 360° and tilt up or down by 90°. The vehicle has two propulsion thrusters for forward and backward motion and four thrusters for attitude control enabling it to move up, down, left, and right, and to turn.

Use of the swimming type ROV significantly reduces the reactor bottom inspection.

Suction-type Wall-climbing Inspection ROV

The suction-type wall-climbing inspection ROV is designed to inspect the shroud which is one of the structural components inside the reactor. Fig. 8 shows the appearance of the ROV and the region it is able

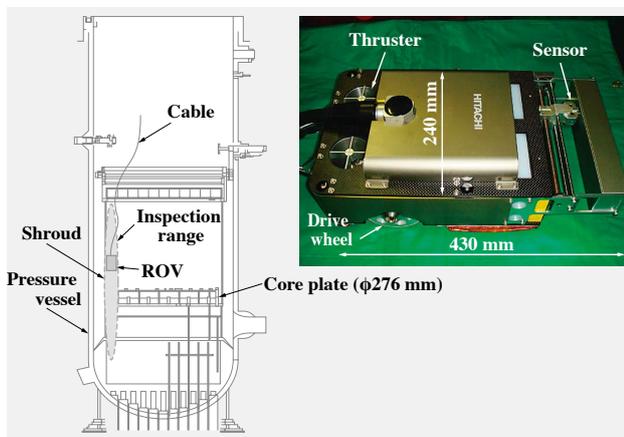


Fig. 8—Appearance of Suction-type Wall-climbing Inspection ROV and Region it is Able to Inspect.

The figure shows the suction-type wall-climbing inspection ROV and the shroud it is used to inspect.



Fig. 9—Portable Guided Wave Inspection System.

The appearance of the portable guided wave inspection system and pipe sensor unit is shown.

to inspect. Because the ROV needs to pass through a 276-mm-diameter hole in the core plate to gain access to the bottom part of the shroud, it was made 240 mm wide and 110 mm high. For propulsion, the ROV has two thrusters for attaching itself to the wall and two drive wheels that it uses to move about on the wall once attached. In addition to being fitted with an eddy current sensor and ultrasonic sensor, the ROV also has a mechanism for scanning the sensors.

Use of the suction-type wall-climbing inspection ROV significantly reduces the inspection time and the associated attendant tasks compared to the mast type inspection device used in the past.

GUIDED WAVE INSPECTION SYSTEM FOR PIPING

Although measurement of wall thinning in piping has, in the past, required the removal of all the heat insulation used to clad the pipes, Hitachi has developed a portable guided wave inspection system that can screen several tens of meters of pipe for wall thinning at a time but only requires a small amount of heat insulation to be removed (see Fig. 9). Key features of the system are that a sensor containing a piezoelectric element can be attached directly to the piping and that use of proprietary signal processing significantly improves detection performance. The system can detect cross-section area change only 1%, not only in straight piping but also in small-diameter curved pipes.

For large-diameter pipes, a partially attached guided wave sensor is currently under development with the aim of identifying the location of wall thinning within a comparatively small range from the sensor (see Fig. 10). The walls of a sample length of pipe used to test the performance were thinned by 3% of the cross-sectional area around 180° of the pipe for case b and by 5% around 270° for case c. The pipe had a 500A diameter and a thickness of 9.5 mm. Fig. 11 shows the results of measurements using a partially attached sensor at 60-degree intervals around the circumference. The amplitude of the reflection increases when the partially attached guided wave sensor is facing the thinning at positions b and c and this makes it possible to identify the position in the circumferential direction over short distances.

Currently, collection of field data from actual power plants is in progress and the testing procedures are being established. The system is intended to be used on actual plant in the future.

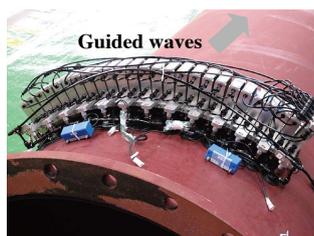


Fig. 10—Partially Attached Guided Wave Sensor. The appearance of the partially attached guided wave sensor used for large-diameter pipes and similar is shown.

NONDESTRUCTIVE TESTING TECHNICIAN TRAINING AND TECHNICAL DEVELOPMENT

While the advanced inspection techniques described above are being developed for the nuclear power industry, the training and retention of the technicians who will use these new techniques, and the passing on of the know-how of technicians skilled in existing techniques are growing in importance.

At our NDE (nondestructive examination) Center which serves as a base to bring together inspectors and equipment at a single location to meet the diverse needs of our customers, Hitachi is working hard to respond to this call by developing inspection equipment that incorporates advanced technology and by strengthening the technical skills of inspectors with the aim of relentlessly improving inspection technology.

CONCLUSIONS

This article has described technical developments in the field of advanced inspection technology for nuclear power plant equipment, including phased array ultrasonic testing, ROVs (submersible remotely operated vehicles) for inspecting inside the reactor, and guided-wave wall-thinning inspection of piping, and also the training and other support for nondestructive testing technicians.

Currently, the environment for nuclear power is undergoing a major change and the ensuring of plant safety and reliability is becoming increasingly important as expectations for nuclear power generation grow. Hitachi is contributing to the development of the nuclear power industry by developing more advanced inspection technologies and nondestructive testing technologies that enable inspection to be performed in more realistic and reliable ways, and by working to improve the skills of inspectors.

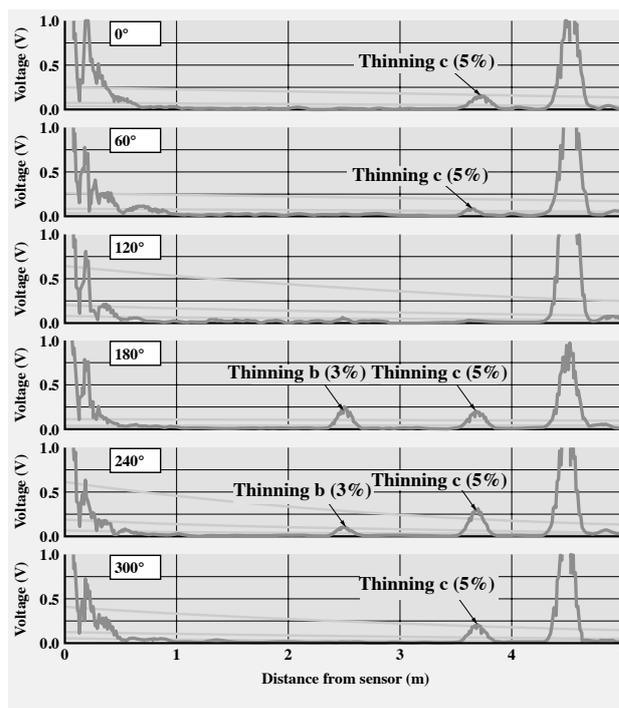


Fig. 11—Example Measurement Using Partially Attached Sensor.

Test result for a 500A pipe with simulated thinning is shown.

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ABOUT THE AUTHORS

**Mitsuru Odakura**

Joined Hitachi, Ltd. in 2003, and now works at the Nuclear Systems Quality Assurance Department, Nuclear Plant Service QA & NDI Section, Hitachi-GE Nuclear Energy, Ltd. He is currently engaged in the development of nondestructive inspection techniques for nuclear power plants.

**Masahiro Koike**

Joined Hitachi, Ltd. in 1982, and now works at the Nuclear Systems Quality Assurance Department, Hitachi-GE Nuclear Energy, Ltd. He is currently engaged in the development of nondestructive inspection techniques for nuclear power plants. Mr. Koike is a member of The Japan Society of Mechanical Engineers.

**Yoshiaki Nagashima, Dr. Eng.**

Joined Hitachi, Ltd. in 1993, and now works at the Ultrasonic Testing Group, Nuclear Inspection & Maintenance Project, Energy and Environmental Systems Laboratory, Power Systems. He is currently engaged in the development of ultrasonic inspection techniques. Dr. Nagashima is a member of the AESJ.

**Yutaka Kometani**

Joined Hitachi, Ltd. in 1990, and now works at the Nuclear Equipment Design Department, Mechatronics System Design Section, Hitachi-GE Nuclear Energy, Ltd. He is currently engaged in the design of nondestructive inspection systems for nuclear power plants.

**Masahiro Tooma, Dr. Eng.**

Joined Hitachi, Ltd. in 1982, and now works at the Inspection System Group, Nuclear Inspection & Maintenance Project, Energy and Environmental Systems Laboratory, Power Systems. He is currently engaged in the development of nondestructive inspection techniques and robotics. Dr. Tooma is a member of the Atomic Energy Society of Japan (AESJ) and The Physical Society of Japan.