High-Efficiency Inspection Service of Plant Facilities Utilizing Ultrasonic Technology that Contributes to Process Shortening

MIKIYASU URATA*1 YUKI KUBOTA*2

YUSUKE ISHIMOTO*3 TAKAYUKI WADA*4

HIROYUKI OHYAMA*5

In thermal, nuclear, and other power generation plants, there is a need to shorten the periodic inspection process, and the establishment of highly efficient inspection services is desired. However, since the inspection of corrosion thinning of plant piping and boiler heat transfer tubes entails incidental work such as temporary scaffolding and removal of scale on the outer surface of the tubes, there is an issue of reducing the time and cost associated with such incidental work. As a measure to address the issue, we have developed an inspection service that can efficiently screen the wall thinning of plant piping with minimal incidental work, and an inspection service that can measure the wall thickness and inner scale thickness of boiler heat transfer tubes without removing the outer surface scale. These services reduce the amount of incidental work required for the inspection of corrosion thinning in plant facilities, which contributes to shortening the periodic inspection process.

1. Introduction

Since power generation plants, such as thermal and nuclear power plants, operate under high-temperature, high-pressure, and corrosive environments for a long period of time, which risks damaging various facilities due to aging deterioration. In particular, plant piping such as main water pipes and main two-phase flow pipes, as well as heat transfer tubes in thermal power boiler facilities, have incurred tube thinning damage due to corrosion and wear [(1)]. The risk of such damage increases especially in aging plants, and the importance of periodic maintenance management is expected to increase. However, in recent years, there is strong demand to shorten the periodic inspection period (process) and to reduce inspection costs [(2), (3)]. Therefore, there arises an issue of the establishment of maintenance technology that can both improve the reliability and reduce the period and cost for facilities that have an increased risk of damage.

In response to this, Mitsubishi Heavy Industries, Ltd. (MHI) has developed a technology that can accurately and efficiently inspect facilities at risk of damage, and offer this technology as inspection services to our customers. This report introduces two examples of our inspection services: a corrosion thinning screening service for plant piping using guided waves and a pretreatment-free inspection service for boiler heat transfer tubes using EMAT (Electro Magnetic Acoustic Transducer).

2. Issues of conventional inspection methods for plant piping and boiler heat transfer tubes

First, this paragraph describes examples of damage to plant piping and the issue of conventional inspection methods. As shown in **Figure 1**, plant piping may incur corrosion thinning

*1 Electron Physics Research Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.

*2 Service Engineering Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.

*3 Business Department, Steam Power Maintenance Innovation Business Division, Energy Systems, Mitsubishi Heavy Industries, Ltd.

*4 Chief Staff Manager, Business Department, Steam Power Maintenance Innovation Business Division, Energy Systems, Mitsubishi Heavy Industries, Ltd.

*5 Chief Staff Engineer, Engineering Department, Steam Power Maintenance Innovation Business Division, Energy Systems, Mitsubishi Heavy Industries, Ltd.

such as FAC (Flow Accelerated Corrosion) and CUI (Corrosion Under Insulation) on its inner and outer surfaces, so it is necessary to periodically inspect piping to understand the occurrence of damage. The methods to understand the damage condition, for example, ones for plant piping of thermal power generation facilities, are described in Codes for Thermal Power Generation Facilities -Rules on Pipe Wall Thinning Management for Thermal Power Generation Facilities(4) issued by the Japan Society of Mechanical Engineers. In this code, periodic inspection and trend monitoring of corrosion thinning for main water pipes and main two-phase flow piping are required. Currently, plant piping inspections mainly employ ultrasonic wall thickness measurements and visual inspections, but depending on the inspection site, temporary scaffolding and removal of thermal insulation may be necessary, resulting in a significant amount of time and cost for the incidental work necessary for the inspection. In addition, shortening the periodic inspection process has been promoted recently, and in some cases, the inspection target areas are limited based on past inspection records and actual results. However, depending on the plant operating conditions, the areas targeted for inspection may not always be the areas with the greatest risk of damage. Therefore, for the inspection of the piping for corrosion thinning, there is an issue of establishing a highly efficient inspection method that can minimize the amount of incidental work and quickly inspect areas with the risk of damage without any omissions.

Next, this paragraph describes examples of damage to heat transfer tubes in boiler facilities of thermal power plants and the issue of conventional inspection methods. Boiler heat transfer tubes may incur sulfide corrosion of the furnace evaporator tubes shown in **Figure 2** and pitting corrosion of the inner surface of the tubes, and as is the case with plant piping, ultrasonic wall thickness measurements and visual inspections are performed. As a parameter for life evaluation with respect to creep damage occurring in boiler heat transfer tubes, it is necessary to know the temperature of the metal exposed during boiler operation. One of the methods for this purpose is to measure the thickness of the inner surface scale (steam oxidation scale) formed on the inner surface of the tube using ultrasonic to estimate the metal temperature based on the thickness (5). This measurement for both the wall thickness and the inner surface scale is performed by applying an ultrasonic probe (sensor) to the outer surface of the tube and analyzing the ultrasonic signals from the sensor to measure the respective thicknesses. However, the outer surface of boiler heat transfer tubes is covered with outer surface scale (atmospheric oxide scale), which needs to be removed before inspection, and the removal of this outer surface scale requires sandblasting or grinding with a grinder, which results in a significant amount of time and cost. Therefore, for the inspection of boiler heat transfer tubes for corrosion thinning, there is an issue of establishing an inspection method that can eliminate the removal of outer surface scale, which is a bottleneck in reducing the time and cost of the inspection.

The next and subsequent chapters describe the technologies and services we have developed to address these issues.

Figure 1 Example of damage to plant piping (flow accelerated corrosion (FAC))

Figure 2 Example of damage to boiler heat transfer tube (sulfide corrosion, with outer surface scale removed)

3. Plant piping damage screening technology using guided waves

3.1 Configuration of inspection system using guided waves

To address the issues related to plant piping inspection described in Chapter 2, we considered it is effective to have a technology that can inspect a wide area at a time for a single inspection point. Therefore, we focused on guided waves, which propagate over longer distances (several meters to several tens of meters) in the metal of piping than ultrasonic waves often used in nondestructive inspection, and developed a plant piping damage screening technology using guided waves. **Figure 3** shows the system configuration of the piping damage screening technology using guided waves. We considered that guided waves are ultrasonic waves that can propagate over long distances in the longitudinal direction of the pipe [6] and are effective for screening corrosion thinning that has occurred in piping. The principle of wall thinning detection is the same as that of general UT (Ultrasonic Testing) technology: guided waves transmitted from the sensor in the longitudinal direction of the pipe are reflected at the point where the cross-sectional shape of the pipe changes, such as wall thinning, and the sensor receives the reflected wave to evaluate the presence or absence of wall thinning.

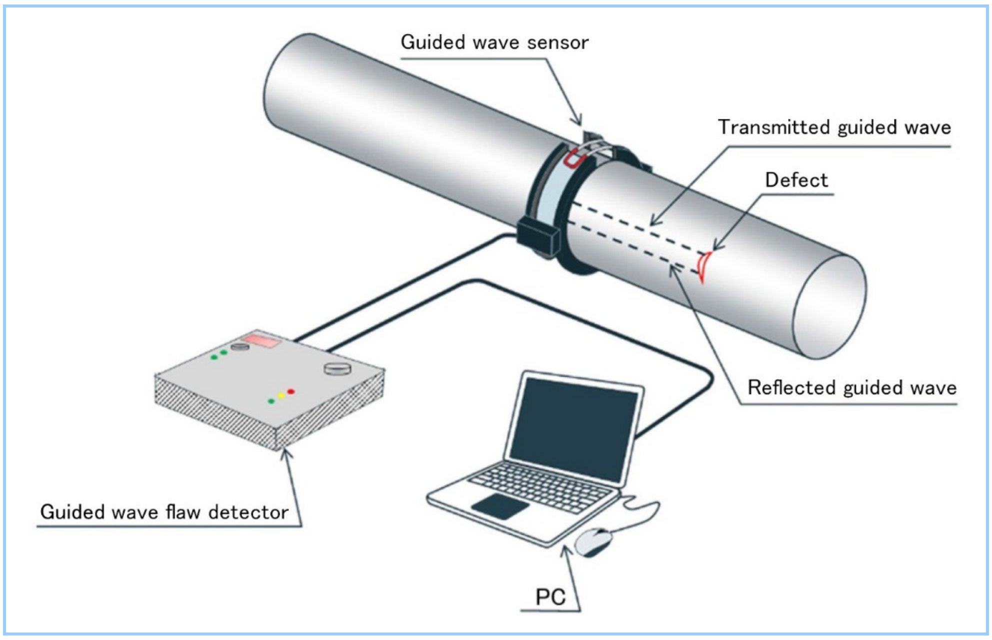

Figure 3 System configuration

Figure 4 shows the developed guided wave sensor. This sensor is a ring-shaped, multi-channel type having multiple transmitting and receiving channels in its circumferential direction. By processing the signal obtained from multiple receiving channels using the FMC/TFM (Full Matrix Capture and Total Focusing Method) [7] to improve SNR (Signal-to-Noise Ratio), this sensor is capable of detecting defects in the elbow area, where the guided wave technology was thought to be difficult to apply in the past [8]. The inspection results are also displayed as a color map processed by FMC/TFM, allowing for visual understanding of the location information of reflection sources such as wall thinning and cross-sectional shape changes. An example of the output of the inspection results is shown in the verification test results in section 3.2.

Figure 4 Guided wave sessor

3.2 Verification test using mock-up pipe

Figure 5 shows the results of the verification test using a mock-up pipe. The mock-up used was a Φ216.3-mm-long straight pipe (200A carbon steel pipe) with a length of 11 m including welds. To the outer surface of the mock-up pipe, an artificial defect simulating pitting corrosion (cross-sectional defect ratio 1%) was applied 5 m from its end, and an artificial defect simulating extensive wall thinning (cross-sectional defect ratio 1.7%) was applied 10 m from its end, where the cross-sectional defect ratio is the ratio of the projected area of the defect to the cross-sectional area of the sound section of the pipe. The results of the verification test of the straight mock-up pipe showed that reflective signals were detected at all defect locations.

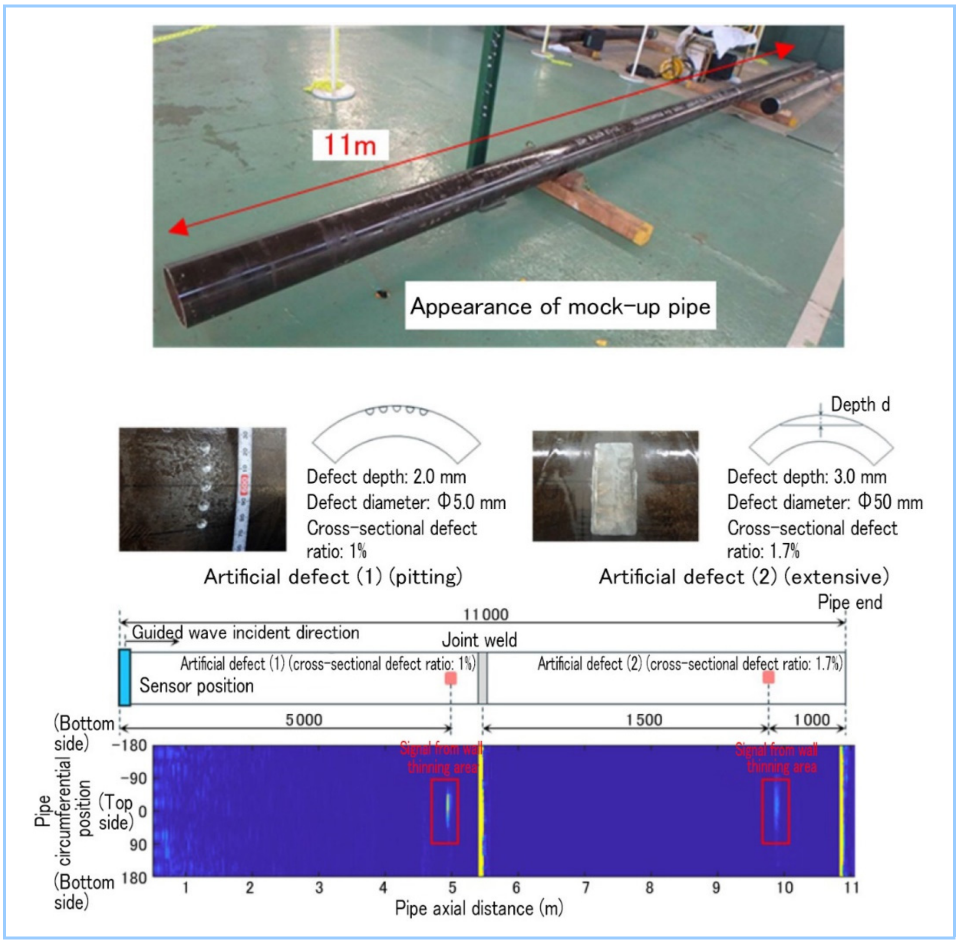

Figure 5 Mock-up pipe verification test results (straight pipe)

Figure 6 shows the results of the verification test using a mock-up pipe with an elbow section. An artificial defect with a cross-sectional defect ratio of 1.5% was applied to the outer surface of the mock-up pipe on the back side of the elbow section. As a result of the verification test, signals with sufficient SNR were obtained from the artificial defects at the elbow section. Therefore, it was determined that the technology could be applied to the elbow section as well. This technology can evaluate the presence or absence of wall thinning in the longitudinal and circumferential positions of the pipe, but it cannot measure the wall thickness.

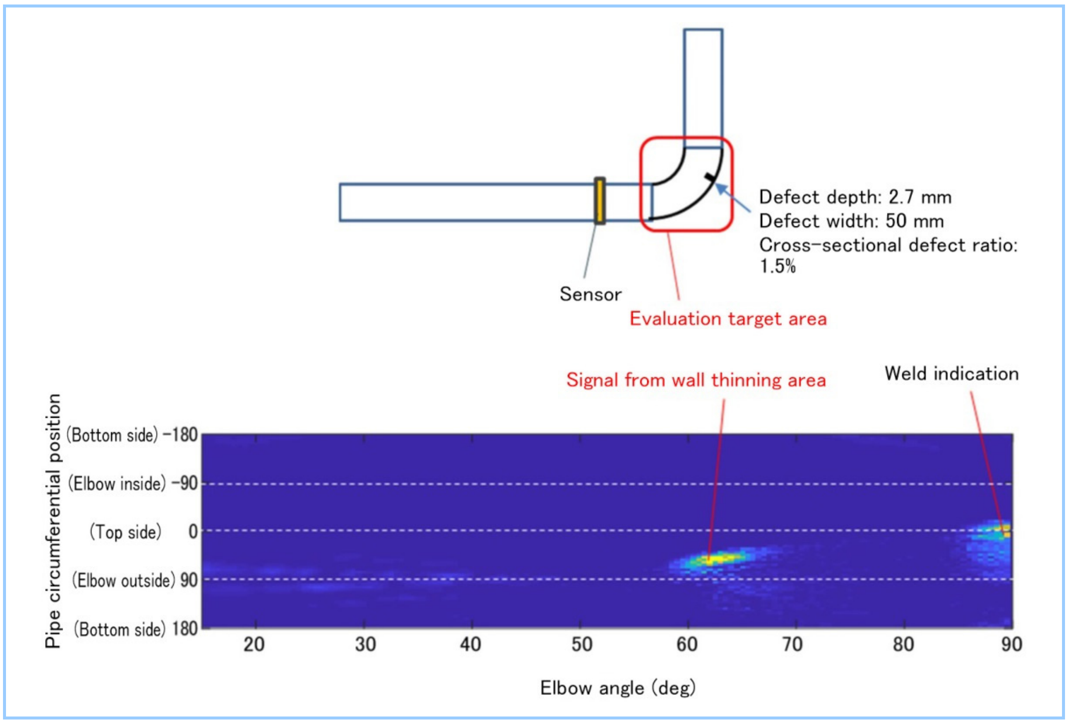

Figure 6　Mock-up pipe verification test results (elbow)

3.3　Result of verification test in actual plant

To evaluate the applicability of the developed inspection system using guided waves to actual plant piping, we conducted verification tests using an actual main water pipe with thermal insulation. **Figure 7** shows an example of the verification results. As a result of the verification in the actual plant, no significant wall thinning was observed with the guided wave, but the influence of pipe ancillaries could be confirmed. Specifically, such ancillaries were the circumferential welds and thermal insulation lugs of the main piping, which could be distinguished from defects by comparing them with the drawing information. In addition, the system was able to detect the reflected signal from an ancillary 10 m away, confirming that it is possible to inspect a range of 10 m on one side from the sensor (20 m maximum, because the sensor can transmit signals on both sides).

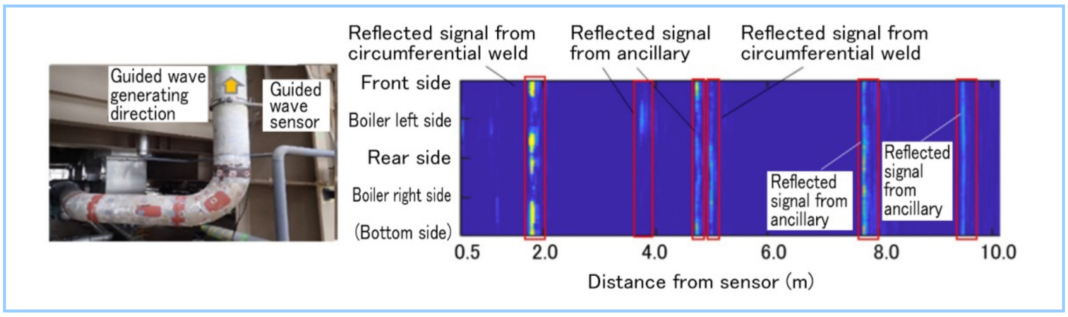

Figure 7　Result of verification test in actual plant piping

3.4　Services using this technology and value provided

Table 1 compares plant piping inspection using a conventional inspection method and plant piping damage screening technology using guided waves. As described above, conventional plant piping inspections require temporary scaffolding and removal of thermal insulation each time. On the other hand, in the case of the inspection using guided waves, although it is necessary to remove the thermal insulation from the sensor installation area, it is not necessary to remove the thermal insulation from the entire inspection area, thereby minimizing the amount of incidental work. In addition, while conventional inspections are based on fixed-point measurements, this technology can evaluate the presence or absence of damage over an area of up to 20 m at a time, making it possible to efficiently screen a wide area of damage.

Based on the result described above, we believe that offering a screening service using this technology will minimize the amount of incidental work, which will contribute to reducing inspection costs and shortening the process of periodic inspections, the critical path of which is the piping inspection. Furthermore, the service can provide customers with the results of a wide range of inspections more quickly than conventional inspections, which reduces the risk of extending periodic inspections due to replacement work associated with the piping inspection and the risk of missing the most damaged areas due to the limited time frame, thereby contributing to ensuring the reliability of plant facilities and the stable supply of electric power.

Table 1 Comparison of conventional method and guided wave technology developed by MHI

Item	Conventional method (typical UT)	Guided wave technology developed by MHI
Temporary Scaffolding	Entire inspection area	Part of inspection area
Removal of thermal insulation	Entire inspection area	Part of inspection area
Pipe surface treatment	Grinding required	Grinding not required
Sensor installation	-	One-touch installation (contact medium required) Installation time: approx. 10 min/place
Flaw detectability	Capable of evaluating wall thickness at the position of wall thinning	Detection only
Inspection range	Fixed point	Wide range (20 m maximum)
Straight pipe inspection	Possible	Possible
Elbow section inspection	Possible	Possible (One area only)
Evaluation of flaw detection	Determination by waveform (wall thickness value)	Visual determination of the presence or absence of flaw detection by imaging the composite waveform (obtains information on the position of wall thinning in the circumferential direction of the pipe as well as in the axial direction)

4. Pretreatment-free inspection technology using EMAT

4.1 Principle and appearance of EMAT

To solve the issues related to boiler heat transfer tube inspection described in Chapter 2, we considered that it is effective to have a technology that can measure the wall thickness of a tube from above the scale formed on the outer surface of the tube. Therefore, we focused on electromagnetic ultrasonics, which enables non-contact thickness measurement by generating eddy currents on the outer surface of a heat transfer tube even when outer surface scale is formed there, and developed a measurement method using an EMAT capable of generating electromagnetic ultrasonic waves. **Figure 8** shows the appearance of the EMAT and **Figure 9** shows its configuration. An EMAT mainly consists of a permanent magnet and a coil, and electromagnetic ultrasonic waves are generated by applying a high-frequency current to the coil (9). The wall thickness measurement method is similar to the conventional ultrasonic wall thickness measurement. The EMAT is placed on the outer surface of the tube to be measured. Electromagnetic ultrasonic waves are applied to the inner surface of the tube, and the reflected signal from the inner surface is detected. The wall thickness is calculated from the arrival time. The developed EMAT has a permanent magnet of optimized size and a coil of optimized wire diameter and number of turns in order to increase the signal intensity of the ultrasonic generated by the excitation.

Figure 8 Appearance of EMAT

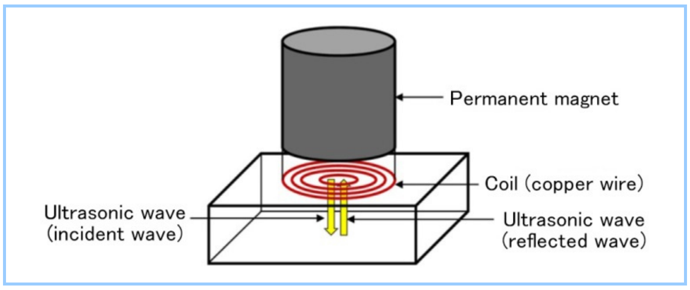

Figure 9　Configuration of EMAT

4.2　Verification test using actual boiler heat transfer tube

In order to evaluate errors in measuring wall thickness and measuring oxide scale thickness on the inner surface of a tube using the developed EMAT, verification tests were conducted using actual boiler tubes with oxide scale on their outer surface as shown in **Figure 10** as test pieces. Specifically, the wall thickness and inner surface scale thickness of the test pieces were measured using EMAT and then compared to the actual wall thickness and inner surface scale thickness obtained from the cross-sectional information observed in the subsequent cutting survey. The maximum thickness of the outer surface scale generated on the test pieces was approximately 1.2 mm.

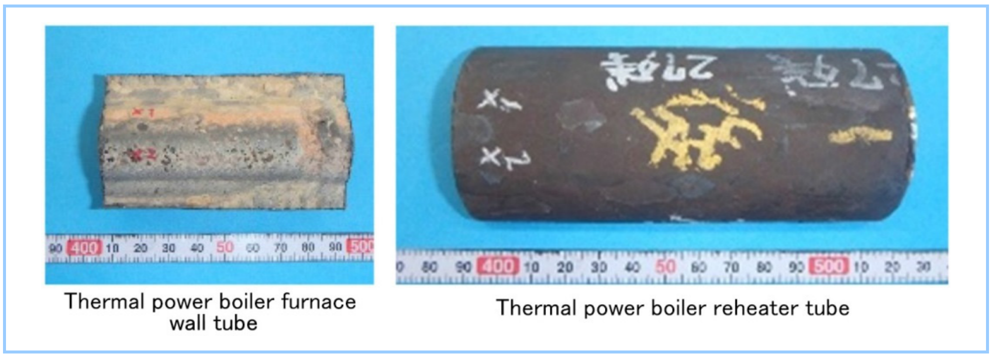

Figure 10　Appearance of actual equipment samples

Figure 11 compares the wall thickness values measured by using EMAT and those actually measured. **Figure 12** compares the inner surface scale thickness values measured by using EMAT and those actually measured. The error in the wall thickness value measured by using EMAT with respect to that actually measured was ±0.2 mm or less. The error in the inner surface scale thickness with respect to that actually measured was ±50 μm or less. This indicates that both cases attained measurement with high accuracy.

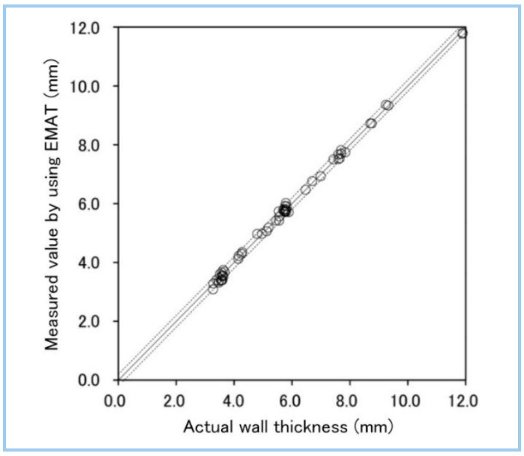

Figure 11　Verification test result (wall thickness)

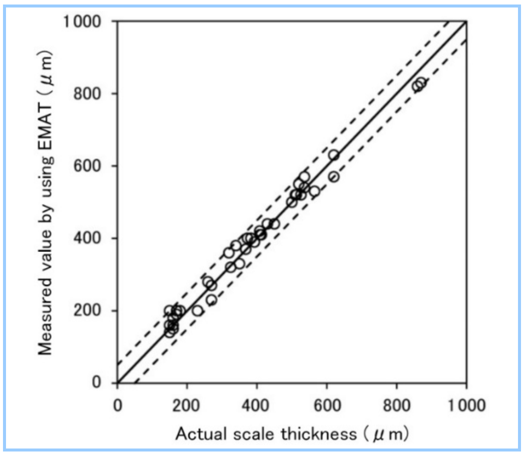

Figure 12　Verification test result (tube inner surface scale thickness)

4.3　Services using this technology and value provided

Figure 13 compares man-hours required for inspection between the conventional method using UT and the developed method using EMAT. The application of EMAT eliminates the need for the removal of outer surface scale, which was conventionally required, and is estimated to reduce man-hours by about 50%, depending on the conditions. In addition, since scale removal by sandblasting generates dust, other operations such as welding cannot be carried out simultaneously in many cases, but this technology allows other operations to be carried out simultaneously. Furthermore, this technology can prevent wall thinning of heat transfer tubes due to sandblasting.

Based on the result described above, we believe that offering our customers inspection services for corrosion thinning of heat transfer tubes using this technology will contribute to reducing the time and cost of the removal of outer surface scale and to shortening the process of periodic inspections, the critical path of which is the inspection or other work on heat transfer tubes.

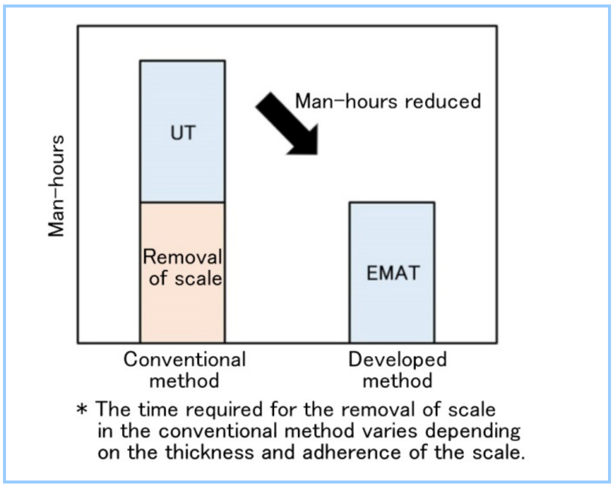

Figure 13　Image of man-hours reduction due to EMAT

5. Conclusion

This report described a damage screening technology using guided waves that minimizes the incidental work required for inspection of corrosion thinning occurred in plant piping and enables efficient inspection, and a pretreatment-free inspection technology for the wall thickness and oxide scale thickness of boiler heat transfer tubes. The guided wave damage screening service has been applied to two plants and the pretreatment-free inspection service using EMAT has been applied to six plants. We believe that this service can contribute to both improving the reliability of equipment with increased risk of damage and reducing the inspection period and cost described in Chapter 1. We will continue to contribute to improving the reliability of plant facilities and shortening the periodic inspection process by providing highly efficient inspection services that satisfy our customers.

References

(1) Hiroshi Akamine et. al, Current Status and New Technologies of Water Treatment in Thermal Power Plants (Non-Toxic Oxygen Scavenger, Japan Industrial Standard Revision, Water Quality Diagnosis), Mitsubishi Heavy Industries Technical Review Vol.58 No.1 (2021), p1~7

(2) Susumu Shiizuka et. al, Development of Maintenance Technology - Measures against Aging Deterioration / New Inspection System / Advanced Operation -, Mitsubishi Heavy Industries Technical Review Vol.57 No.4 (2020), p 1~9

(3) Efforts to Further Improve Utilization and Long-term Operation of Nuclear Power Generation, The Federation of Electric Power Companies of Japan, 2021 （in Japanese）

(4) Codes for Thermal Power Generation Facilities -Rules on Pipe Wall Thinning Management for Thermal Power Generation Facilities- JSME S TB1-2016, The Japan Society of Mechanical Engineers, 2016

(5) Hiroshi Susukida et. al, Research on High Temperature Steam Oxidation of Austenitic Stainless Steel, Mitsubishi Heavy Industries Technical Review Vol.8 No.4 (1971), p93~100

(6) Vinogradov S.et al., Magnetostrictive Transducer for Torsional Guided Waves in Pipes and Plates, Materials evaluation, 3 (2009), p 333-341.

(7) Hongwei Hu.et al., Ultrasonic Phased Array Sparse-TFM Imaging Based on Sparse Array Optimization and New Edge-Directed Interpolation,　Sensors, 18, 2018

(8) Toshihiro Yamamoto et. al, Correlation between Defect Location and Defect Sensitivity in Inspection of Pipe Elbows by Guided Wave Testing, Conference Proceedings of Thermal and Nuclear Power 2016, p6-10

(9) Fumio Kojima, Basic Principles and Recent Trends in Ultrasonic Inspection Using Electromagnetic Acoustic Transducer, Journal of The Society of Instrument and Control Engineers, Vol. 56 No.11 (Nov. 2017), p839-844