Latest Welding Ultrasonic Testing Technology Contributing to Shorten On-site Construction Period (UT in lieu of RT)

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With regard to on-site modification and periodic inspection of power plants, there is a strong demand for reducing the required work period from the viewpoint of securing a stable power supply. The work generally involves welding of piping. As their post-weld quality inspection, radiographic testing (RT) is usually employed. However, RT needs to follow radiation safety management, which sometimes serves as a bottleneck in achieving a shorter work period. Mitsubishi Heavy Industries, Ltd. (MHI) developed the process and technology so that ultrasonic testing (UT) can be performed in lieu of the conventionally applied RT for quality inspection. The application of UT has enabled other necessary work and inspections to be conducted simultaneously, making it possible to shorten the work period substantially.

1. Introduction

From the viewpoints of energy transition and carbon neutrality, initiatives to achieve better efficiency and decarbonization of power generation facilities have been accelerating in recent years. As part of the strategy for how to adapt coal-fired power generation facilities to suit the needs of the future, Japan's "Future Thermal Power Plant Policy (March 2023)" proposed by the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry provides forecasts about improvements such as high efficiency and low-carbonization by existing facilities by 2030, on the condition that stable power supply is maintained(1). In response, MHI has laid out plans such as the road map for decarbonization of existing infrastructure. The initiatives, for example, to add high value to equipment according to the current market needs (e.g., decarbonization and efficiency improvement of the customers' facilities in operation) are thus being promoted(2).

The key to maintaining stable operation while making use of existing equipment is periodic inspection. Specifically, it means to conduct an inspection with insight into damage form, and timely upgrades. Moreover, in recent years, thermal power generation facilities have been facing tougher operating conditions because of the necessity of daily start and stop (DSS) or weekend start and stop (WSS) operation. There is also a growing need for rapid recovery to handle power demand even in the case of incidents such as steam leakage(3)(4).

In order to conduct on-site modification or periodic inspection, the plant is shut down for a certain period. A long-term shutdown not only affects the profit from the operation, but also has a considerable impact on society from the viewpoint of power supply. The more prolonged the work period, the greater the impact. It is therefore necessary to minimize the work period and improve the availability of the plant.

However, as the plant consists of various kinds of piping and other components, there is a great variety of parts that need to be modified or inspected. Their required processes are also

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varied. During modification or periodic inspection, different types of work need to be done. For example, some parts are modified or replaced. For others, their integrity is checked and then, if needed, appropriate measures are taken. Completing such multitasked work as fast as possible necessitates the identification of a critical path that determines the course of the work, in addition to other initiatives such as securing the viability of simultaneous execution of a series of work processes, and reducing the time on standby between the processes. For example, the boiler is one of the main components of a thermal power plant. Upgrading or modification of its parts such as the furnace wall, burner or heat transfer tubes may involve large-scale on-site welding of more than several thousands of joints, depending on the project. RT is generally used to inspect the quality of these welds. In conducting RT, however, some restrictions are imposed for safety control reasons, including setting up a radiation controlled area and keeping other workers out of such area. This makes it difficult to simultaneously conduct other tasks such as welding, inspection and repair. Especially in large projects involving multiple mixed tasks, in some cases, RT procedures caused a setback for achieving a shorter work period.

Given such circumstances, MHI has been working on the development and application of UT with the employment of ultrasonic that is harmless to the human body. The purpose is to solve the issues caused by conventionally applied RT in the projects requiring the work to be completed as fast as possible. The following chapters give a detailed definition of UT as an alternative to RT (i.e., the technology and process of UT used in lieu of RT, applied to the piping that is excluded from welding self-inspection). Our UT technology developed by MHI and its application examples are also presented.

2. Definition of our UT as alternative to RT (interpretation of standards and scope of applicability)

2.1 Overview of RT and UT

RT is a non-destructive test in which a product is irradiated with radiation to examine the internal defects and state based on the change in the intensity of radiation that has transmitted through the product. A defect can be identified based on the film onto which it is projected, thus excelling in the objectivity and recording of test results. However, because of the use of radiation harmful to the human body, its conduct entails a certain level of restrictions such as setting up a controlled area and keeping other workers out of the area. On the other hand, while UT is also a non-destructive test, ultrasonic is propagated inside the product to detect internal defects based on the acoustic properties. Ultrasonic is an elastic wave propagating inside materials and is harmless to the human body. Unlike RT, UT does not require any special measures such as setting up of a controlled area. In UT, however, ultrasonic from the sensor held by hand is allowed to directly enter the product. The results are interpreted watching the receiving waveforms. Higher skill levels are therefore required of the inspector than RT, while the objectivity and recording of test results are inferior to RT.

2.2 Japanese standards for post-welding inspection

Both RT and UT are essentially categorized as the techniques of inspecting the inside of a product (volumetric inspection). However, RT is generally used to inspect the quality inside the joints after on-site welding. One of the reasons for this is the stipulation by the Japanese standards. The scope of welding self-inspection is determined by Articles 79 and 80 of the Enforcement Regulations of the Electricity Business Act(5)(6). Therein, RT is stated as the non-destructive test method for welding self-inspection on the grounds of Appended Table 24 of the Interpretation on the Technical Standard for Thermal Power Plant(7)(8). No other methods are specified.

2.3 Definition of UT as alternative to RT

However, if pipes have an outer diameter of less than 150mm, the applicable non-destructive testing of welds is not limited to RT. These pipes are outside the scope of welding self-inspection according to the Enforcement Regulations of the Electricity Business Act, described in Section 2.2.

We focus on the pipes to which RT has been conventionally applied despite them being outside the scope of the aforementioned standards. The process and technology of UT described in this report are therefore intended to be applied to these pipes instead of RT.

3. Criteria, verification process and application technology of UT as alternative to RT

3.1 Setting out criteria for technology of UT as alternative to RT, based on relevant domestic/overseas standards

An overseas example of criteria for UT as an alternative to RT is the standards set by the American Society of Mechanical Engineers (ASME), which are called ASME Boiler and Pressure Vessel Code(9). Having been standardized as the Ultrasonic Examination Used in lieu of Radiographic Examination, etc., it is widely applied. However, as described the previous chapter, Japan has currently no domestic standards on UT, to be used as an alternative to RT. Considering how the boiler has been inspected based on Japanese domestic RT standards in Japan, it is considered practical that these RT standards also underlie the inspection with UT.

The domestic standards for RT applied on the boiler welds can be found in Appended Table 25 of the Interpretation on the Technical Standard for Thermal Power Plant, and the corresponding JIS. Based on the allowable defect sizes specified therein, the criteria for UT were formulated. ASME codes were referred to for the height (depth) of defects such as planar cracks, because no reference standards were available.

3.2 Practicality verification of UT as alternative to RT

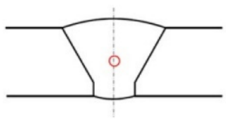
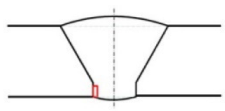
3.2.1 Characteristics of UT technology for verification

Considering the capabilities to detect and identify defects and the objectivity and recording of test results, we decided to employ a phased array (PA) UT method. In PAUT, the probes are multiple elements that are arrayed in series. The timing of transmitting/receiving ultrasonic waves is electronically controlled to perform scanning or focusing of combined waves at an arbitrary angle. The flaw detection results are obtained in the form of images, enabling the detection and examination of a product's internal defects. MHI was the early adopter of PAUT for power plant maintenance and integrity assessment. Specifically, it has been applied in technologies such as detection of creep damage in welded pipes(10). We have therefore decided to make use of our long-accumulated expertise such as knowledge on PAUT and probe design know-how, to establish the technology of UT as an alternative to RT.

Moreover, adaptive UT, in which defects are examined with straight beam vertical flaw detection placed on the reinforcement of weld, is employed as needed in addition to PAUT with angle beam flaw detection. In the adaptive UT technology, the combination of array probes and soft gel enables ultrasound to directly enter from the uneven surfaces such as reinforcements of weld. The inside of a product can be accurately visualized by applying Full Matrix Capture/Total Focusing Method (FMC/TFM). This adaptive UT technology is one of the advanced UT techniques that MHI has been developing ahead of its competitors(11). Unlike the aforementioned PAUT with angle beam flaw detection, it allows ultrasound to enter in the direction vertical to the axis of the pipe as in the case of RT. Typical UT with angle beam flaw detection have difficulty in detecting and evaluating certain forms of welds, complete joint penetrations (root concavities and excessive penetrations) and such. However, adaptive UT can be expected to handle such difficulty and distinguish defects from welded shapes.

3.2.2 Verification procedure

Figure 1 shows an example test piece into which artificial defects have been incorporated based on the criteria described in Section 3.1. Besides artificial defects, we also prepared several other test pieces with various season defects such as blow holes and poor penetration. These defects in test pieces were examined multiply by multiple methods: UT, RT, X-ray CT and cross-section survey. The association between the detectability and the defect size was determined. The validity of the criteria was also assessed.

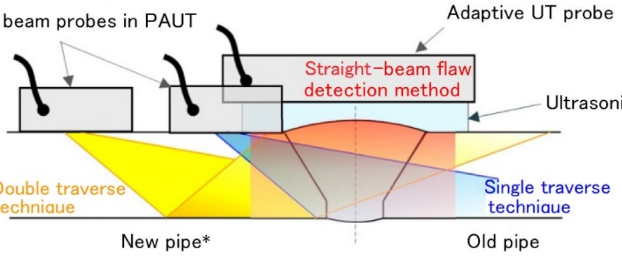
	Class 1 defect (round blow holes or similar defects)	Class 2 defect (elongated slag inclusions, pipes, poor penetration, lack of fusion or similar defects)
Class 1 defect score (size) allowable maximum limit*1	1mm	≤3mm in length
Artificial defect	Side drilled hole: ϕ 1mm 	Slit by electric discharge processing 3 mm (Length) × 11 %t (Height)*2 

*1 Based on Appendix 4, JIS Z 3104: Defect classification based on radiographic images
*2 Based on, as an example, the standards for calibration test pieces specified in Section V Article 4

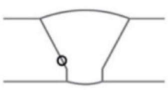
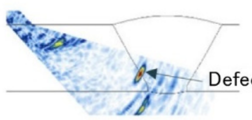
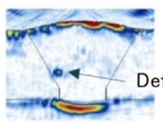
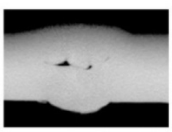
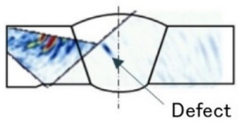
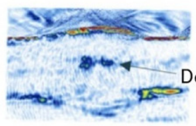
Figure 1 Test pieces for verification of UT as alternative to RT (with artificial defects)

3.2.3 Verification results

Figure 2 gives a schematic representation of UT on welds and actual images of artificial and season defects. The use of PAUT with angle beam flaw detections enabled the defects in welds to be detected and evaluated with high sensitivity using the two methods of direct irradiation and single reflection. Adaptive UT with vertical beam flaw detection from the reinforcement of weld allowed defects in welds and shapes of welds to be quantified objectively for evaluation. A large number of artificial and season defects were examined likewise, to formulate the framework of criteria for the UT as an alternative to RT. In addition to the verification using test pieces, many on-site inspections were carried out, thereby making sure that there were no problems from the viewpoint of workability as well. The final decision for the application to actual units was made after discussion with the customer (electricity generation utility) based on these verification results.



(a) Schematic representation of ultrasonic testing of welds

Defect example	PAUT with angle beam probes	Adaptive UT
Artificial defect (Side drilled hole) 	 Defect echo	 Defect echo
Season defect  Cross-sectional confirmation result by X-ray CT*	 Defect echo	 Defect echo

※ X-Ray Computed Tomography

(b) Examples of ultrasonic testing images of welds

Figure 2 Results of UT as alternative to RT

3.2.4 Discussion and future directions

As described so far, the test pieces used for verification were prepared based on the allowable defect sizes specified by the RT standards for boiler tube welds in Japan, before advanced UT technologies such as PAUT and adaptive UT were applied for examination. It has been demonstrated that their capabilities to detect and identify defects and the objectivity and recording of test results are comparable to RT, indicating that UT can be used instead of RT.

In UT, however, multiple types of special probes, which MHI has developed, need to be used properly depending on the tube specifications (tube diameter, wall thickness and material). There is also the issue of only a limited number of inspectors having the skills required by the testing. Therefore, MHI is focusing on the improvement of efficiency and sophistication of the UT as an alternative to RT by utilizing automation technology in addition to the latest signal processing technology. Specifically, the implementation is in progress through evaluating the effectiveness of the latest UT technologies such as Phase Coherence Imaging (PCI) based on the defect detectability and criteria, whose validity has been verified by PAUT, and the self-driving capability in which robotics systems are incorporated. The automatic assessment and determination system for which our vast amounts of accumulated defect images and evaluation logic are utilized is also in development now. In MHI Group, the group-wide adoption of the latest technologies that should be incorporated in the UT as an alternative RT has been attempted. All of our offices, group companies and Research & Innovation Center are working together to verify the effectiveness, establish and improve the inspection process, and improve the skills of inspectors. These initiatives are coming to fruition.

4. Practical application of UT as alternative to RT and its effects

While optimizing the UT technique and process, UT has been conducted on several tens of thousands of welds in over 20 projects. In the most recent case of a large modification in 2022, for example, nearly 10,000 tube welds in the furnace evaporator were inspected by UT. As a result, the period that it took to complete the periodic inspection was reduced by 10 days (from 104 days to 94 days), although there were also contributions from other initiatives. To benefit from simultaneous conduct of UT and sharing of defect images, the pass/fail judgment of test results was immediately given as the feedback, which helped reduce the time on standby as well. As shown in **Figure 3**, adaptive UT visualizes information such as the location of any defect and the penetration of root pass in each cross-section, thereby revealing each welder's unique attributes (e.g., where defects tend to occur or how deeply root pass penetrates). This has also helped improve the quality and so on.

Looking forward, we will keep promoting group-wide initiatives to expand the application of UT as an alternative to RT, focusing on the plant projects in which the work needs to be completed as fast as possible. Its use as a tool to support rapid plant recovery from incidents such as steam leakage will also be promoted.

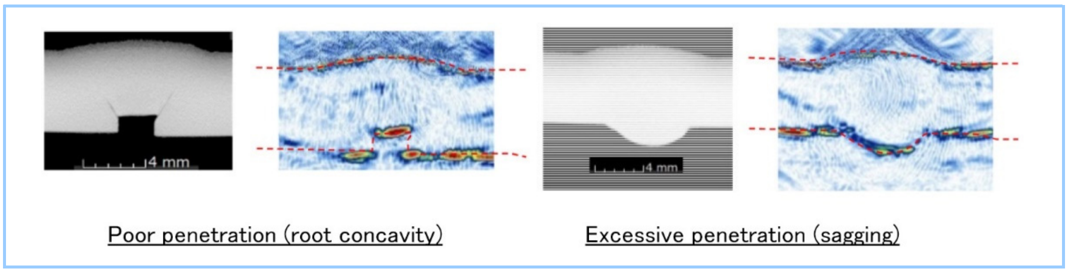


Figure 3 Visualization of penetration of root pass using adaptive UT

5. Conclusion

Power plants are required to shorten the period necessary for periodic inspection. Especially regarding the boilers in these plants, this report presents the technology of UT used in lieu of RT, whose application to an actual unit is in progress as a measure to minimize the period of on-site modification and inspection. When this technology was practically applied, some of the restrictions conventionally mandated by radiation safety management in the case of RT were lifted, resulting in a shorter work period.

This UT as an alternative to RT is only applied to where it does not conflict with the scope of the current Japanese standards. However, this is a case in which the value (i.e., a considerably reduced work period) was successfully created by changing the conventional process in an attempt to meet a strong customer need. We will further make the technology advance and expand its applicability, thereby offering more value to society.

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