



Guided Wave Pipe Inspection and Monitoring System

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In recent years a very large number of UT inspections have been performed to detect wall thickness reduction of feed water pipe, etc. These inspections are accompanied by heat insulation removal and restoration work throughout the inspection range. In order to enable efficient execution of such a great number of tests, a new method of pipe damage detection and monitoring has been developed which makes it possible to inspect a long range of pipe with one sensor, using the ultrasonic characteristics of so-called "guided wave." This new technique has drastically reduces the work of heat insulation removal, scaffolding and restoration. This method has also made it possible to reduce inspection work itself. This report introduces the results of some pipe damage detection tests performed using the method described above and shows an outline of the application of the system to a thermal power plant.

1. Introduction

In the maintenance of thermal power plant piping systems dealing with wall thickness reduction of feed water pipe, etc., a very large number of UT inspections have been performed in recent years by removing the heat insulation work over the entire testing area and spending much time and labor. In the meantime, the applicability of a long-range testing method using guided wave has been confirmed in the petrochemical industry in the United States and this method has already been used for pipeline, etc.⁽¹⁾ As this technique enables reduction of the testing cost and provides sophisticated maintenance techniques by structural health monitoring, it would be used widely for application to piping in thermal power plants, etc. in the future. This report deals with the guided wave pipe inspection and structural health monitoring system (G-Monitor) built up through various verification tests of piping in thermal power plants. Fig.1 shows the system of the G-Monitor.

2. Role sharing between G-Monitor and UT inspection

The role sharing between G-Monitor and UT inspection can be better understood by the image of an iceberg shown in Fig. 2. By using conventional UT method, we can only see part of the iceberg and it is difficult to image the whole of it. So in a manner of speaking, the role of the G-Monitor is to figure out the whole picture of the iceberg, and the role of the UT inspection is to test in detail the part of the iceberg that is visible above the water.

Specifically, in the inspection of piping in a thermal power plant, the G-Monitor is used for detecting damage existing within a pipe length of 5 to 15 meters as a screening tests and immediately determines the degrees and positions of such damage. The UT inspection then performs its main role of carefully investigating each defect found by the G-Monitor.

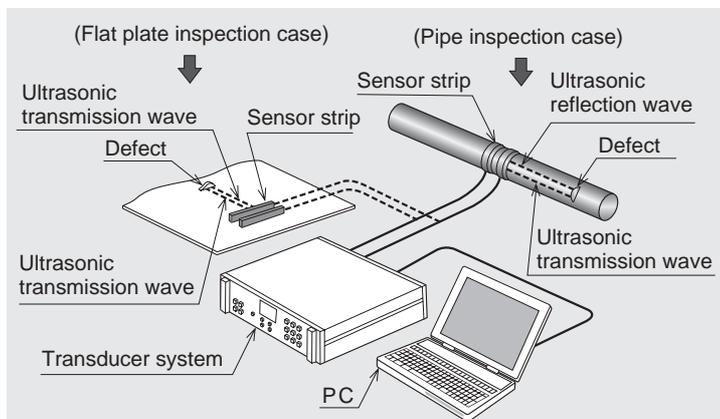


Fig. 1 System of guided wave pipe inspection and monitoring
 This system is composed of a sensor comprising pieces of magnetstrictive strip of Ni, etc. and coils, a transducer system and a PC for controls.

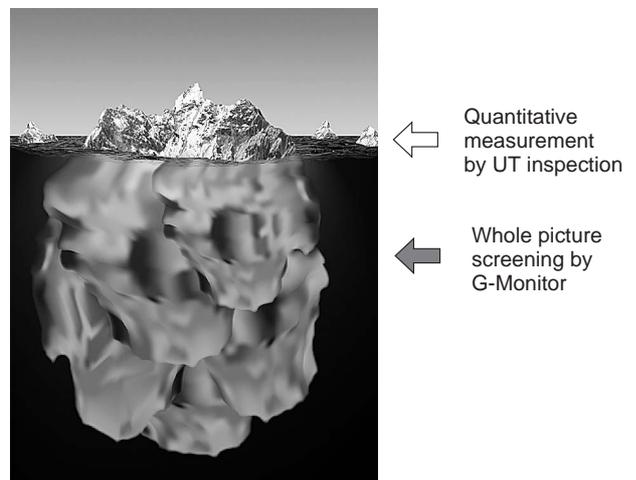


Fig. 2 Image of iceberg whole picture screening by G-Monitor

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3. Outline of G-Monitor system

So-called guided wave means the ultrasonic wave propagated in the axial (longitudinal) direction in the test specimen. To understand such characteristics, the surge of a tsunami may be imaged. When the tsunami encounters a small obstacle, its level rises only a little to override the obstacle.

On the other hand, its level rises greatly to override a large obstacle encountered. Such an obstacle may be likened to a defect and the tsunami water level to the echo oscillation amplitude. Fig. 1 shows the system of the G-Monitor, which transmits the guided wave (having such characteristics) to the pipe. Pieces of strip of a metal such as Ni are bonded to the outer surface of the pipe using an adhesive and lead wires are wound on their outer surfaces like coils to form a sensor. The guided wave transmitted from the sensor propagate in the axial direction of the pipe, and when there is a section area loss in the pipe due to the existence of a flaw or a wall reduction, a transmitted wave is reflected from that position. The distance from the sensor to the damage portion can be estimated in terms of the round traveling time from sensor through the damaged portion. The size of the area reduction can be estimated by the echo amplitude of the reflected wave.

4. Advantages of inspection by using G-Monitor

Fig. 3 shows the advantages of this monitor system. The sensor to be used consists of pieces of approximately 0.2 mm thick magnetostrictive strip material, an adhesive and coils. Since total sensor thickness including such

- Inspection can be implemented over a long range
 - ⇒ Inspection of a 5 - 15m range is possible.
 - ⇒ Sensor installed in a position with scaffolding is capable of covering positions without scaffolding.
 - ⇒ Use for primary damage screening
 - Detailed inspection to be performed by UT inspection.
- Sensor can be set up easily
 - ⇒ One sensor can be installed in 90minutes.
- Environmental protection taken into consideration
 - ⇒ One sensor is capable of covering a wide range, reducing work of heat insulation and waste materials.

MHI is now applying for a patent for this system.



Pipe wound with pieces of strip of Fe-Co, etc.

Fig. 3 Advantages of guided wave pipe inspection and monitoring system

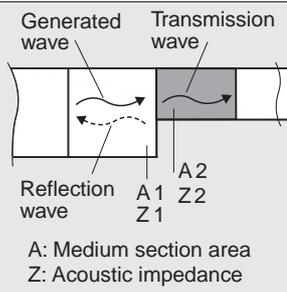
as strips and coils is only approximately 4 mm thick, the heat insulation can be re-installed easily with the sensor in place. Therefore, even in locations where scaffolding for heat removal and restration is required, long time measurement can be done just installing longer lead wires. (Measurement is possible without repeating scaffold placement, heat insulation removal and restoration).

Further, since a low frequency guided wave, which shows low attenuation, is used and the wave is propagated in the axial direction of the pipe for long distance, damage such as a flaw or corrosion detection within a 5-15 m range from the sensor is possible. Accordingly, it is not necessary to remove the heat insulation over the entire range to be tested as in the case of UT inspection. In other words, inspection can be done just removing the heat insulation around the sensor installation position, and spending time for the heat insulation covering and materials wastage can thus be reduced drastically.

5. Principle of flaw detection by guided wave

Fig. 4 shows the principle of guide wave reflection at the point where pipe wall thickness loss has been occurred. The transmitted wave is reflected at the point of acoustic impedance change that indicates the resistance change in ultrasonic wave propagation. The acoustic impedance is expressed by the section area, density and sound velocity in the material so that when the material and temperature are the same, the acoustic impedance depends solely on the section area. Therefore, a reflection wave is generated where the section area changes. For this reason, it is also understandable that wall thickness reduction occurred at both inner and outer surface can be detected

In case of stepped section change



A: Medium section area
Z: Acoustic impedance

- ① Acoustic impedance Z (ultrasonic wave propagation resistance)

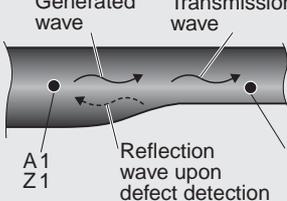
$$= A \text{ (section area)} \times \rho \text{ (density)} \times \nu \text{ (sound velocity)}$$
- ② Ultrasonic wave reflection ratio: R

$$R = \frac{\text{Reflection wave}}{\text{Generated wave}} = \frac{Z1 - Z2}{Z1 + Z2}$$

↓

- The reflection ratio of guided wave changes in response to change in the section area.
- When wall thickness is reduced, the reflection ratio takes a positive value. When it is increased, the ratio takes a negative value.
 → Reflection wave shifts 180 deg. to reverse the amplitude.

In case of gradual change



Reflection wave upon defect detection

Fig. 4 Principle of guided wave reflection at point where wall thickness is reduced

Reflection wave is generated at a point where wall thickness is reduced as the acoustic impedance that expresses the ultrasonic wave propagation resistance changes at such point.

6. Positions where G-Monitor is capable of performing measurement

Various verification tests were performed with a view to applying the G-Monitor to piping at thermal power plants. Results confirmed that this system is capable of detecting gradual pipe wall thickness loss as well as flaws in straight pipe, pipe elbow and pipe diameter reducer. Fig. 5 shows an example of where in the thermal power plant piping system the G-Monitors may be installed. The results of the various verification tests performed are described below:

6.1 Detection of gradual reduction of pipe wall thickness

Wall thickness reduction of pipe in service is usually

prone to be in the axial direction. Reduction area detection tests were performed on pipes artificially simulating three types of defects: a gradual axial direction wall reduction 3 mm in depth and 400 mm in length; 3 mm in depth and 200 mm in length, and a 3 mm depth notch like defect. Here, the artificial defects section loss ratio was 10% in all three specimens. Fig. 6 shows the results of the measurement tests. Although the echo amplitude values of the two artificial gradual thinning areas were approximately half of the value at the notch like defect, amplitude due to the reflection from those two gradual thinning showed twice as high as the noise. This test results indicates that gradual thinning can be detected by guided wave inspection

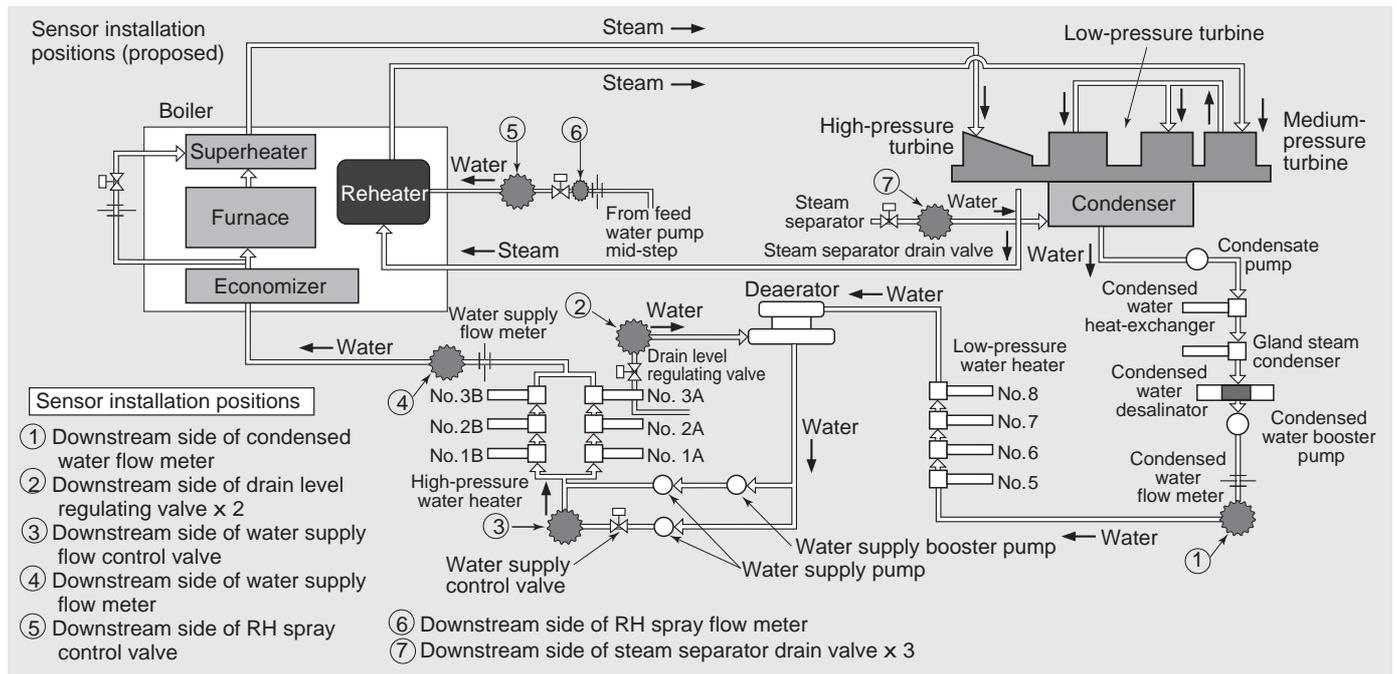


Fig. 5 Example of G-Monitor installation at thermal power plant

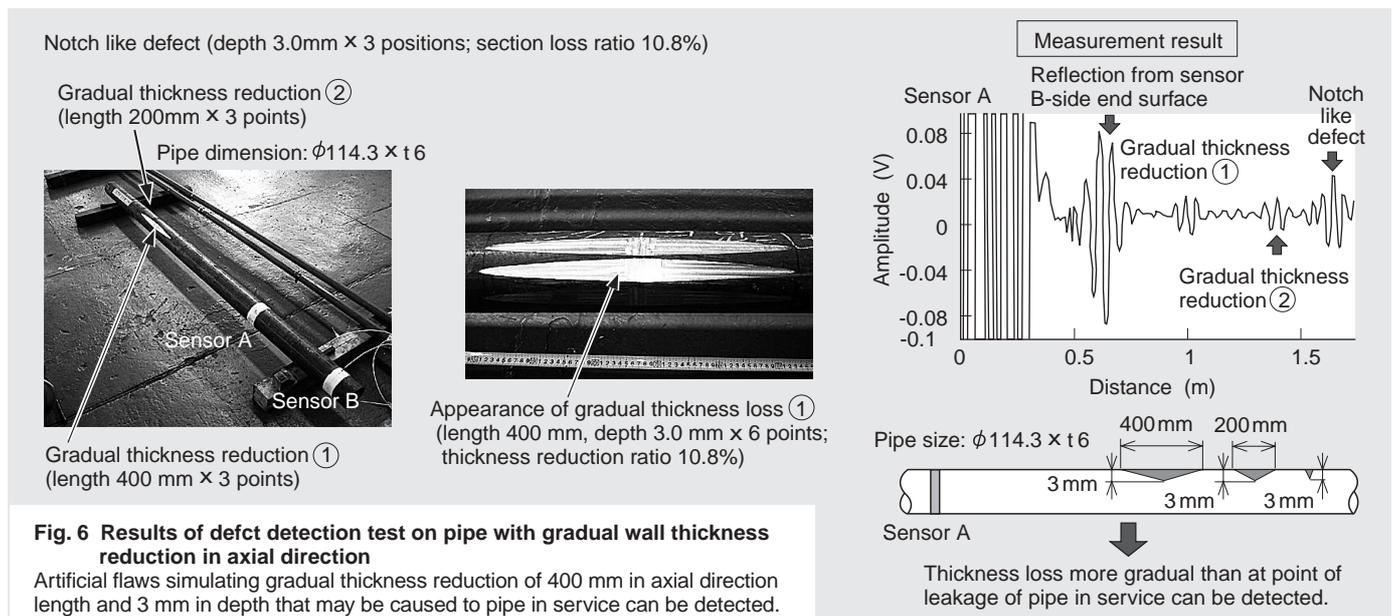


Fig. 6 Results of defect detection test on pipe with gradual wall thickness reduction in axial direction

Artificial flaws simulating gradual thickness reduction of 400 mm in axial direction length and 3 mm in depth that may be caused to pipe in service can be detected.

6.2 Results of checking of defect detection limits

Notch-like artificial flaws were introduced to a straight pipe, elbow and reducer, and their detectability limits were verified.

Fig. 7 shows the measurement result of a cut with a section loss of 1.6% introduced to a straight pipe. The echo amplitude at the cut point is twice the value of the noise level of the range subject to measurement. Flaws of section loss ratios up to 1.6% can thus be detected.

An elbow and reducer with a cut were then subjected to measurement, and it was confirmed that flaws in the elbow with section loss of up to 4.2% and flaws in the reducer with section loss of up to 5.2% could be detected.

6.3 Influences of guided wave attenuation factors

At first it was feared that measurement would hardly be conducted, because of its high attenuation at the geometry changing portion like pipe supporting point or

where the pipe configuration changes. Accordingly, various measurement tests were performed to make sure the influences of various attenuation factors.

Fig. 8 shows the result of measurement at the elbow section. A change was seen in the echo amplitude between the circumferential weld 1 and the circumferential weld 2 before and after the elbow section. Approximately 15% attenuation was found, revealing that guided wave is attenuated in the elbow section.

It was also confirmed as a result of measurement at the reducer section and the U-rod section that the guided wave attenuating at the reducer section and the U-rod section could be ignored.

Fig. 9 shows the positions on the pipe where measurement is possible based on the influences of attenuation factors found as a result of the measurements performed so far.

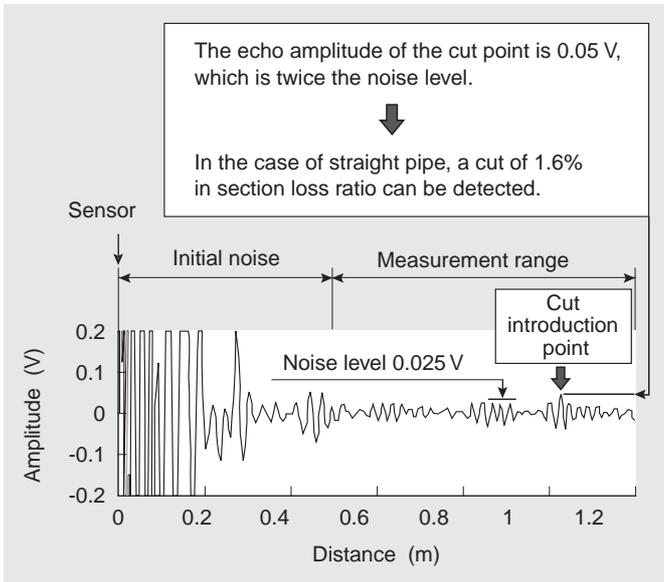


Fig. 7 Defect detection limit in straight pipe
Notch-like cut flaw of 1.6% in section loss ratio can be detected.

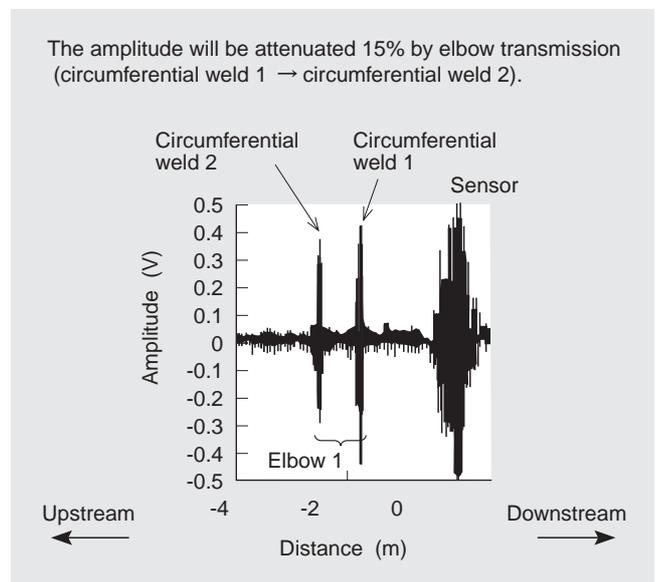


Fig. 8 Elbow section attenuation measurement result
Guided wave is attenuated 15% by elbow transmission.

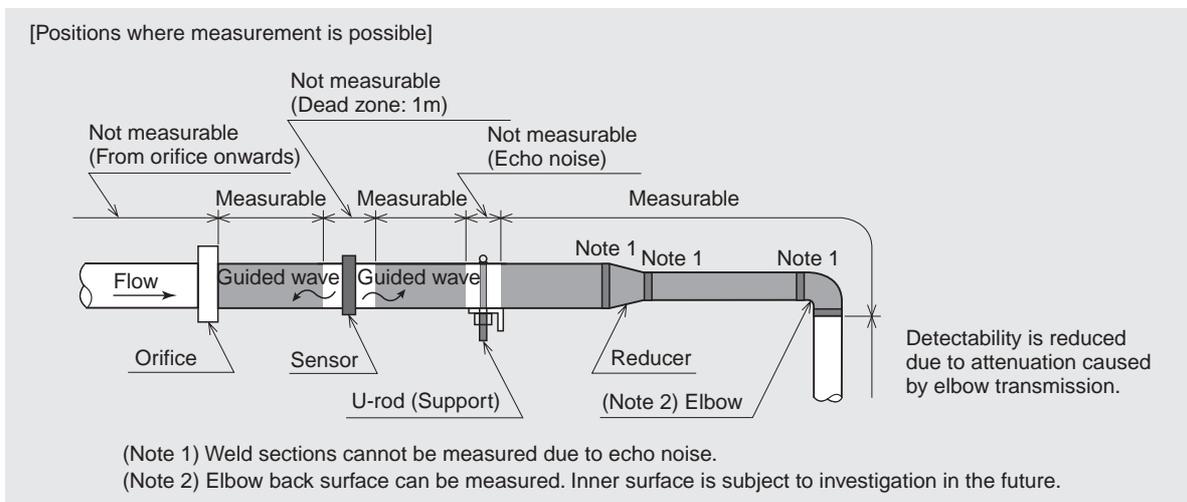


Fig. 9 Positions measurable by system available at present
When guided wave passes the elbow, it is attenuated so that positions after elbow transmission are subject to reduced detectability.

6.4 Temperature conditions to enable measurement

The temperature of piping at thermal power plants rises during operation, and depending on the temperature, monitoring during operation may be difficult. On the other hand, for practical purposes, inspection when the plant is on shutdown may be sufficient, because pipe wall thinning generally proceeds very slowly.

Therefore, in order to clarify the temperature conditions at which measurement is possible, a high temperature measurement test using metal strip sensors for high temperature was performed in an electric furnace. Results confirmed that the sensors could work efficiently as long as the pipe temperature is up to 370°C.

At present, a long-term durability verification test is in progress with a view to monitoring while piping is in operation.



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7. Conclusion and future prospects

We have already reported on a guided wave pipe inspection and monitoring system intended for application to thermal power plants.

This technique drastically reduces the work of heat insulation removal and restoration which has hitherto been required for pipe maintenance and management, and that it is usable as a system that enables pipe damage detection by monitoring at any time.

We will be very pleased if this report contributes to maintenance and management of thermal power plant facilities.

Reference

- (1) Takahiro Hayashi, Circumferential Guided Wave Inspection for a Defect at Inner Surface of a Pipe, ASME-PVP2004 (2004)