Research for Field Application of Heat Exchanger Facilities using Guided Wave

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Abstract Heat exchanging facilities can be divided into meeting flow and parallel flow according to the direction of the moment using the principle of heat transmission. The principle is the application of two types of axially symmetric ultrasonic tube modes and "longitudinal" modes with particle displacement coupled in axial and radial directions for transverse failures and torsional modes, oscillating in the circumferential direction only, for longitudinal failures. And, it is necessary to maintain in the optimum condition for the buried heat exchanging facilities. Particularly, Buried tubes or pipes are not proper method to inspect corrosion condition or decrease of thickness. So. we are performing these facilities through digging only. But, it is very time consuming work for testing a lot of quantity and the speed of the test is not fast also. For the supplementation of this weakness, we are contributed greatly to the improvement of quality through Guided wave system.

Keywords: Guided-wave, mode conversion, dispersion curve, Heat exchanging facilities

1. Summary

Nondestructive test, or NDT for short, is a means of quality control or assurance for materials, mechanical units, and structures and refers to the entire process of testing for surface and internal defects in the test body or assessing the characteristics and internal makeup of the subjct. Amazingly, NDT does all this while retaining the original state of the test body and without the need for damaging, disassembling, or destroying the test body, which can be a material, product, or even a structure[1].

Of the various forms of NDTs, the ultrasonic guided wave technique utilizes a wave that propagates based on the given structure's geometric shape. This particular approach performs with high efficiency in a wide range of NDTs and is therefore applicable to many different fields. In addition, unlike conventional longitudinal wave- or transverse wave-based point-by-point approaches, ultrasonic guided wave technique is not only capable of scanning large facilities in there entirety from a fixed probe point but enables testing with the structure intact and without the need to remove the structure's insulation or coating. In short, ultrasonic guided wave technique is superior to conventional approaches in terms of both time invested and economic efficiency. What's more, the technique is being actively used in applications where thermo-materials or limited space restrict inspection technician's access and for maintenance testing power generation facilities where varying structural shapes make normal ultrasonic testing unfeasible[2-7]. The authors of this study based upon the basic theories of guided wave and tested the wave on various piping and tubing systems of actual power generation facilities and other industrial sites and conducted comparative analysis of the findings against experimental data to achieve a higher degree in evaluation accuracy. In particular, guided wave was applied to testing of tubes, pipes, and other heat exchanging facilities buried underground to present the possibility of a more efficient testing method.

2. Theories

Ultrasonic guided wave progresses to the inside of test bodies carrying free boundaries, such as planes, cylinders, and rectangles. Here, the wave progresses through the entire thickness of the test body in a complex oscillation pattern. Ultrasonic guided wave appears in cases of flat surfaces having a tube or a free boundary. With such unique response, ultrasonic guided wave gets distinguished from longitudinal, transverse, and most other types of ultrasonic waves. Introducing ultrasonic guided wave to a flat surface with a given thickness and a converted frequency results in formation of various modes. These modes, as shown in Figure 2, carry two basic forms: symmetrical and anti-symmetrical. Figure 1 describes ultrasonic guided wave that gets transmitted to 2h-thick flat surface and x instruction in the + direction. Here, micro displacement u is realized through the following equation and based on position scalar ø and displacement vector Ψ:

$$u = \quad \Psi \qquad (1)$$

In the case of Equation (1), the wave is indicated on the secondary surface and the motion path does not rely on coordinate y. Further, position vector Ψ carries amplitude that is not 0 at the y-axis. Position energy ø and Ψ get expressed as longitudinal wave and transversal wave, respectively, and satisfy the following equation:

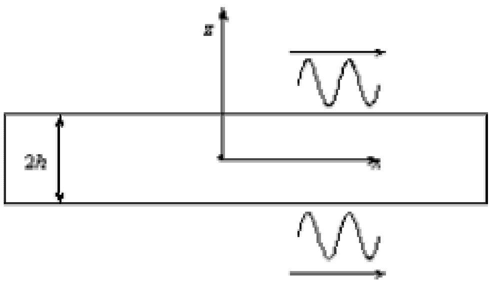

Figure 1. Propagation of a plane harmonic Lamb waves

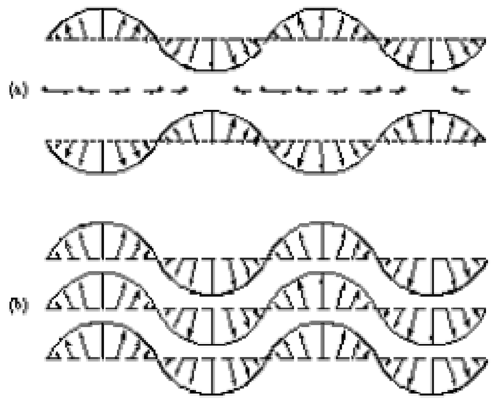

Figure 2. Symmetric (a) and Anti-Symmetric (b) Modes

$$\frac{\partial^2\Psi}{\partial \mathbf{x}^2} + \frac{\partial^2\Psi}{\partial Z^2} + \mathbf{k}_t^2\,\Psi = 0 \qquad (2)$$

(3)

Equations (2) and (3) include two different longitudinal and transversal wave numbers, as shown below:

$$\mathbf{k}_1 = \omega\rho\lambda + 2\mu$$

(4)

$$\mathbf{k}_t = \omega\rho\mu$$

(5)

From Equations (4) and (5), ω is the frequency angle and λ and μ are lamb moduli. In addition, ρ is the medium’s density. U and W, which are micro displacement vector v’s elements from x- and z-axes and get expressed as position energy ø and Ψ through the following equations:

(6)

$$w = \frac{\partial \Psi}{\partial z} + \frac{\partial \Psi}{\partial x} \quad (7)$$

Equations (6) and (7), which are for position values ø and Ψ and the displacement value, are expressed as two wave groups that satisfy each wave's equation of motion and initial conditions. Here, waveform of the first wave group is known as symmetrical ultrasonic guided wave and waveform of the second wave group is known as anti-symmetrical ultrasonic guided wave. Phased array ultrasonic enables dynamic focusing and real-time scanning because it's possible to adjust the direction and shape of the ultrasonic beam transmitted by the electronic scanning. Due to such characteristic, ultrasonic beam having a steering angle comes to carry a special domain angle when progressing inside the material. Ultrasonic wave beam progresses normally inside the material until a defect is met. At such point, majority of the ultrasonic wave returns to the probe due to a variance in acoustic impedance. With phased array ultrasonic wave, the beam that progresses toward a defect progresses with a specific domain steering angle and this makes the ultrasonic beam that's within the special steering angle return to the probe when a defect is met. Here, depending on the size of the defect met, the returning beam also comes to carry a specific domain angle and measuring this angle enables assessment of the defect's size.

3. Test Piece and Testing Equipments

3.1 Test Piece

Figure 3 illustrates the large diameter pipe tested in this study. The pipe has an outer diameter of 508mm and is 19mm thick and 16m long. This pipe was being used to service an actual power generation facility, featured a welding joint in the middle, and was supported by vertical and horizontal hangers and supports. The inner wall along the welding area was deliberately thinned to simulate a defect.

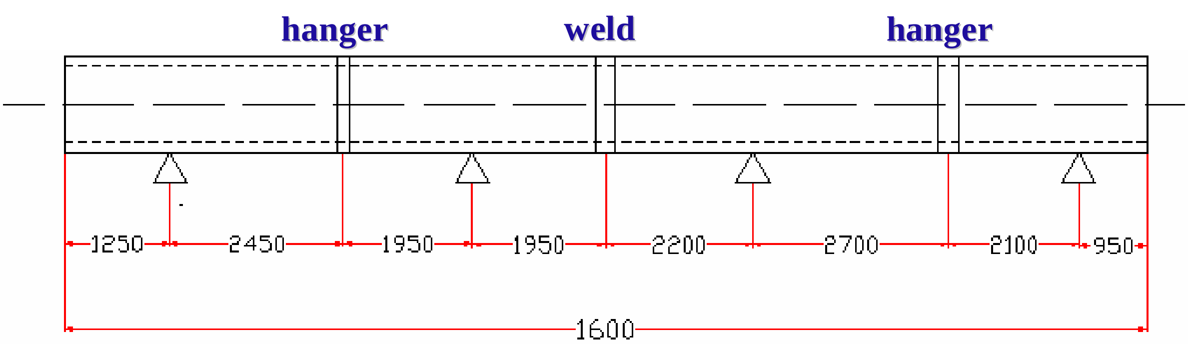

Figure 3. Large Diameter Pipe Specimen Geometrics

3.2 Testing Equipments

In this study the authors utilized GUL's Wavemaker SE16, a long distance ultrasonic guided wave tester, to generate the ultrasonic guided wave and evaluate the structure's welding, defects and defect- or corrosion-induced wall thinning. Modes of ultrasonic guided wave that can be generated from the pipe-like structures used in this experiment include bell-shaped, torsional, and bent modes. On the other hand, the system in this study supports curve-shaped and torsional modes. Figure 4 illustrates the components of this study's ultrasonic guided wave generation system, which are a signal transmitting testing device, a transmission device controlling computer, and a probe.

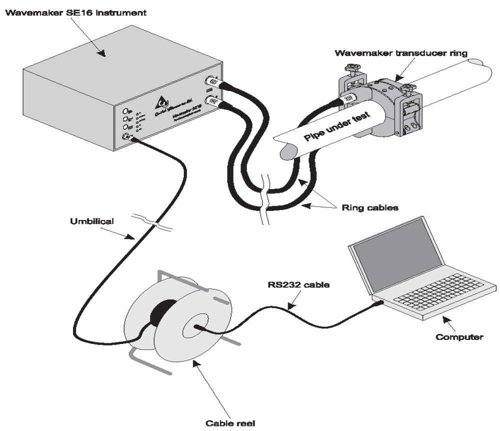

Figure 4. Wavemaker SE16 System Components

4. System Composition and an Application Example

Figure 5. Guided wave inspection for buried heat exchange facilities

Figure 5 is a photograph of an inspection technician evaluating the stability of buried heat exchanging pipes that have been deteriorated from long-term use. He is evaluating thickness changes in the welding areas, pipe bends, and the pipe in general using ultrasonic guided wave to determine the life expectancy of the facilities and to outline the range of their replacements. There are five types heat exchange facilities being tested (250mm, 300mm, 350mm, 500mm, and 600mm), for a total of ten pipes. Each of these pipes was installed with a probe from the system to monitor for localized wall thinnings and thinning statuses. Table 1 lists the specifications of this test.

Table. 1 Test Specifications

No.	V/V No.	Pipe Size (mm)
1	B-01	600A
2	B-29	250A
3	B-09	350A
4	B-16	250A
5	B-13	500A
6	B-21	250A
7	B-23	250A
8	B-25	300A
9	B-28	500A
10	B-32	350A

5. Application Test and Test Results

Figure 6. Inspection of buried Facilities (V/V No.: B-09)

Figure 6 is a photograph of a ultrasonic guided wave sensor that has been installed on the exterior of the test pipe, and Figure 7 illustrates the resultant waveform from the test, for the pipe bends located 2.34m and 5.97m in – direction from the sensor. Here the +F4 section indicates the tee point of the pipe. As can be seen in Figure 6, disappearance of the signal entering the 10m range from the installation point indicates severe corrosion of the pipe and that this corrosion is general and not localized. The green line in the middle of the image is the sensor installation point.

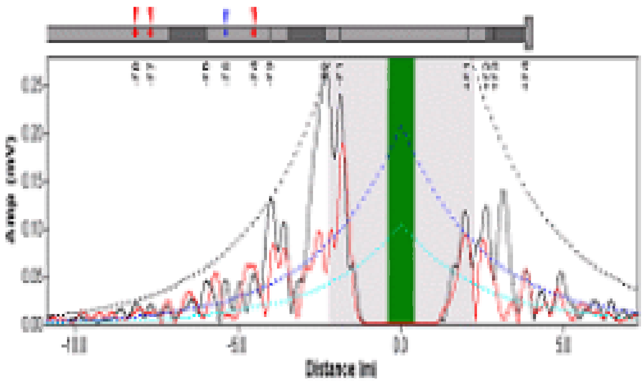

Figure 7. Buried Facilities Test Result (V/V No.: B-09)

(a) Guided wave sensor for inspection (b) Guided wave inspection

Figure 8. Inspection of buried Facilities (V/V No.: B-16)

Figure 8 are photographs of the ultrasonic guided wave test being performed on a buried pipe. Figure 8 (a) shows the sensor installation and Figure 8 (b) shows the testing equipments. Figure 9 illustrates the resultant waveform, where anti-symmetrical waveform along the pipe bend and past the pipe bend is generally very high. Ergo, it was possible to identify an overall corrosion and wall thinning of the pipe.

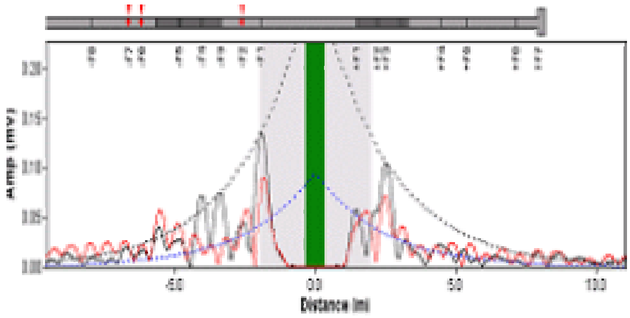

Figure 9. Buried Facilities Test Result (V/V No.: B-16)

Figure 10. Buried Facility (heated)

Figure 10 is a photograph of a buried heat exchange facility that has been heated. As can be seen from the photograph, thick scaling has formed on the surface. Further, analysis of the resultant waveform confirmed severe wall thinning inside the pipe and the authors were thus able to verify that the test pipe was in much worse condition than any other facility. Figure 11 illustrates the resultant waveform for this pipe.

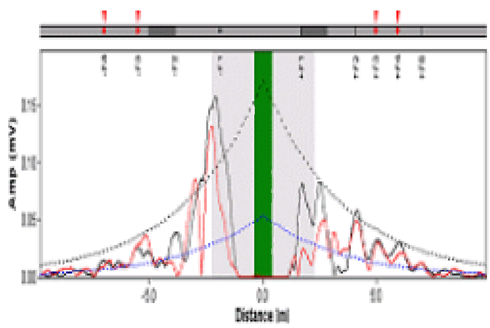

Figure 11. Buried Facility Test Result (V/V No.: B-32)

6. Results and Observations

Table 2. Summary of Test Results

V/V No.	Pipe Size (mm)	Results Summary
B-01	600A	10% to 20% thickness change and localized pinhole formations.
B-29	250A	Partial reduction in both directions.
B-09	350A	Severe corrosion and generalized wall thinning.
B-16	250A	Generalized wall thinning and corrosion.
B-13	500A	Generalized corrosion and wall thinning in the + direction from sensor installation point.
B-21	250A	Generalized corrosion and wall thinning in the + direction from sensor installation point.
B-23	250A	Partial wall thinning between pipe bends in the + direction.
B-25	300A	Generalized corrosion and wall thinning in the + direction of sensor installation point.
B-28	500A	Generalized corrosion and wall thinning.
B-32	350A	Severe localized corrosion both inside and outside the pipe – requires replacement.

Table 2 summarizes the results from ultrasonic guided wave testing on ten buried heat exchange facilities at an actual site. Traffic around the test site was for the most part very heavy and the minor vibrations generated by passing vehicles propagated along the surface of the buried pipes and affected the resultant waveforms. Ergo, it was difficult to realize precise signal analysis but the authors were able to derive fluctuations for the overall state of the pipes. Generalized corrosion was particularly severe in V/V No. B-32 and V/V No. B-09 and their replacement was urgently needed. In addition, the authors feel the rest of the heat exchange facilities should be replaced one by one, preceded by establishment of a replacement plan based on additional scheduled inspections. This site testing revealed that it is easy to determine the status of wall thinnings in the range of 10% to 20% but that thickness change of less than 10% produced a result signal accompanied by externally-sourced noise, which is extremely difficult to distinguish. Ergo, the authors feel further research into distinguishing the signal from noise.

7. Conclusion

By applying ultrasonic guided wave testing to buried tubes, pipes, and other heat exchange facilities the authors attempted to propose the possibility of a more efficient testing method and derived the following conclusions:

1. Applicability of ultrasonic guided wave testing on heat exchange facilities that are installed with insulation and buried facilities was found to be sufficient.

2. Because most of the testing sites were located in the city, the experiment involved significant levels of noise for individual frequencies and thus produced test results in which precise signal distinction was difficult. This was attributed the probe installation point and nearby surroundings.

3. The experiment confirmed the viability of ultrasonic guided wave application to test buried heat exchange facilities and the improved reliability of data gained from precision analysis of the testing signal.

References

[1] E.S. Park, I.G. Park, and S.J. Song, "Nondestructive Evaluation Engineering," Hakyeonsa, pp. 1-2, (2005)

[2] S. J. Song, J. S. Park and H. J. Shin, "Guided Wave Mode Selection and Flaw Detection for Long Range Inspection of Polyethylene Coated Steel Gas Pipes", Journal of the Korean Society for Nondestructive Testing, Vol. 21, No. 4, pp. 406-414, (2001)

[3] D. N. alleyne and P. Cawley, " Long Range Propagation of Lamb Waves in Chemical Plant Pipework", Materials Evaluation, Vol. 52, No. 7, pp. 504-508, (1997)

[4] Y. H. Cho, "Understanding and Application of Ultrasonic Guided Waves", Journal of the Korean Society for Nondestructive Testing, Vol. 21, No. 4, pp. 446-460, (2001)

[5] H. J. Shin, "Nondestructive testing by using guided wave technique", Journal of the Korean Society for Nondestructive Testing, Vol. 20, No. 3, pp. 238-245, (2000)

[6] Tatsuyuki Nagai, masami Hyodo and Kenichi Takamura, "Long Range Ultrasonic Technique for Inspection of Buried Pipelines", Journal of the Japanese Society of Non-Destructive Inspection, Vol. 51, No. 10, pp. 622-627, (2002)

[7] P. J. Mudge and A. M. Lank, "A Long Range Method of Detection of Corrosion under Insulation in process Pipework", Journal of the Japanese Society of Non-Destructive Inspection, Vol. 46, No. 4, pp. 314-319, (1997)