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A Shear Horizontal Waveguide Technique for Monitoring of High Temperature Pipe Thinning

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1. Introduction

Recently, FAC (Flow Accelerated Corrosion) of the carbon steel piping has occurred in the secondary piping in nuclear power plants. In order to monitor a corrosion or FAC in a pipe, there is a need to measure the pipe wall thickness at a high temperature. An ultrasonic thickness measurement method is a well-known and most commonly used non-destructive testing technique for wall thickness monitoring of a piping or plate. However, current commonly available ultrasonic transducers cannot withstand high temperatures of, above 200℃.

Currently, the variation of wall thickness of the pipes is determined by a portable ultrasonic gauge during plant shutdowns. This manual ultrasonic method reveals several disadvantages: inspections have to be performed during shutdowns with the possible consequences of prolonging down time and increasing production losses, insulation has to be removed and replaced for each manual measurement, and scaffolding has to be installed to inaccessible areas, resulting in considerable cost for intervention. In addition, differences of the measurement conditions such as examiner, temperature, and couplant could result in measurement errors.

It has been suggested that a structural health monitoring approach with permanently installed ultrasonic thickness gauges could have substantial benefits over current practices. However, conventional ultrasonic thickness gauging techniques cannot be applied to those high temperature pipes because the piezoelectric ultrasonic transducers cannot be used at high temperatures. The piezo-ceramic becomes depolarized at temperatures above the Curie temperature as well as the difference of thermal expansion of the substrate, couplant, and piezoelectric materials may cause a failure [1].

In order to solve those fundamental problems occurring during the propagation of ultrasound at high temperature, a shear horizontal waveguide technique for wall thickness monitoring at high temperatures is developed. A dry clamping device without a couplant for the acoustic contact between waveguide and pipe surface was designed and fabricated. The shear horizontal waveguides and clamping device result in an excellent S/N ratio and high accuracy of measurement with long exposure in an elevated temperature condition.

A computer program for on-line monitoring of the pipe thickness at high temperature for a long period of time was developed. The system can be applied to monitor the FAC in carbon steel piping in a nuclear power plant after a verification test for a long period of time.

2. Methods and Results

2.1 Experimental Methods

Because the shear horizontal vibration mode shows no dispersion characteristics, i.e., constant wave velocity in a certain frequency range, the ultrasonic signal in the time domain is sharp and clear. Therefore, shear horizontal mode has an advantage to acquire sensitive and accurate experimental data at high temperature.

The shear wave transducers are attached on the edge of the waveguides. A 12.5-mm diameter ultrasonic shear transducer was coupled to the far end of the waveguide to excite and receive the shear horizontal mode. It was coupled by a shear couplant facing cross section of the strip. It was ensured that the polarization direction of the transducer was parallel to the width of the strip. A clamping device that could attach two parallel strip waveguides with a separation of 1 mm to the plate was manufactured (see Fig. 1).

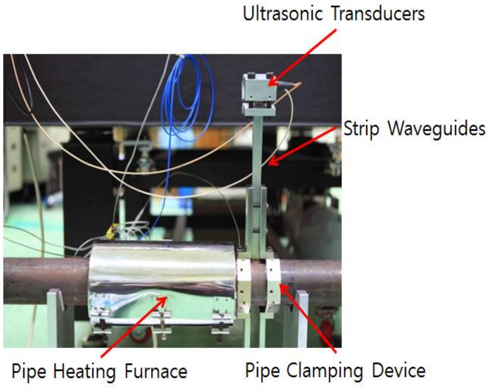


Fig. 1 A pitch-catch waveguide, a clamping device and a test tube with portable furnace.

Because the pitch-catch method shows no main bang signal and a very weak signal from the end of the transmitting waveguide, multiple reflection signals from the back wall of the pipe show a clear and high S/N ratio. The signal from the end of the transmitting waveguide can be characterized for the condition of ultrasonic energy transfer from the waveguide to the pipe, in other words, the condition of acoustical contact between the waveguide and pipe.

A furnace with circular heating elements was installed to the pipe and the temperatures of several points on the pipe were measured by thermocouples. Ultrasonic signals were acquired and processed by an industrial PC. An ultrasonic high temperature thickness monitoring program was developed and the monitoring status is displayed (see Fig. 2).

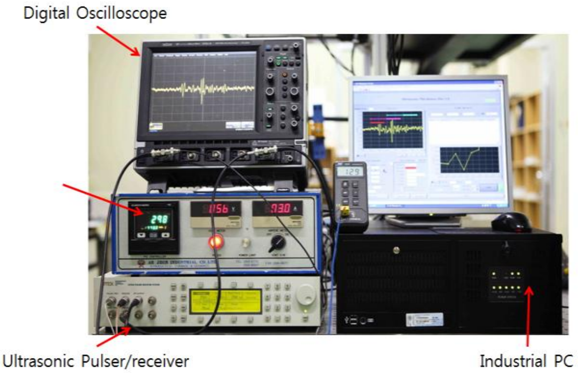


Fig. 2 Experimental setup for high temperature thickness monitoring, including ultrasonic pulser/receiver, furnace controller, digital oscilloscope and industrial PC for control and monitoring.

Fig. 3 shows a typical ultrasonic signal acquired from the pitch-catch type waveguides. A pulser/receiver (Model UT-340, UTEX Corp.) and shear wave transducers with frequency of 5 MHz are used in the experiment. Also, a digital oscilloscope was used for monitoring the ultrasonic rf waveform in the time domain. The signal amplitude is quite high and therefore the S/N ratio is also high. This is because the receiving strip only receives signals that have been transmitted into the plate specimen, which reduces their amplitude but avoids pollution from unwanted strip modes that are excited upon reflection from the strip end. It can be noted that signal clarity and transmission through the joint without considerable distortion is much more important than the transmitted amplitude [2].

In order to measure the flight time of the reflection, moving gates are set in the real time acquisition system. The first gate is set to the signal from the end of the transmitting waveguide. The second gate is set to the first back wall signal, and the third gate set to the second back wall signal. The second gate and third gate are set as moving gates to follow the first gate setting. The peak position of each signal is determined as the flight time, denoted as t_1 and t_2 in Fig. 3.

The shear wave velocity of Stainless Steel is approximately 3,250 m/sec, the flight time to reflect from a 300 mm long strip waveguide is estimated as 180 μsec. The flight time between first back-wall and second back-wall of the 6 mm thick plate is estimated at 3.7 μsec.

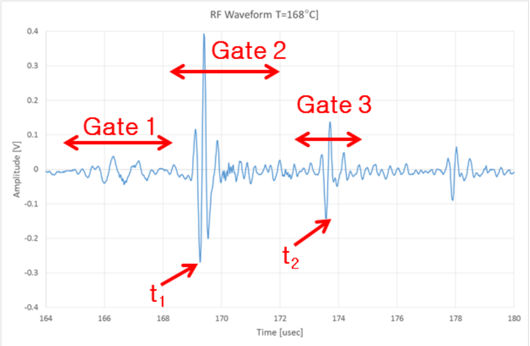


Fig. 3 Typical ultrasonic rf signals at 200℃. The signal acquired by a SH mode waveguide with pitch-catch method. It shows a low amplitude of end-reflection and very high amplitude signal from the back-wall.

2.2Results and Discussion

One of the main sources of error in a high temperature thickness measurement is variation of the ultrasonic wave velocity at high temperature. A very accurate calibration reflecting the relationship between the velocity and temperature is required. The flight time between gates was determined at each temperature and converted into the wave velocity. The relationship between the shear wave velocity and temperature is shown in Fig. 4.

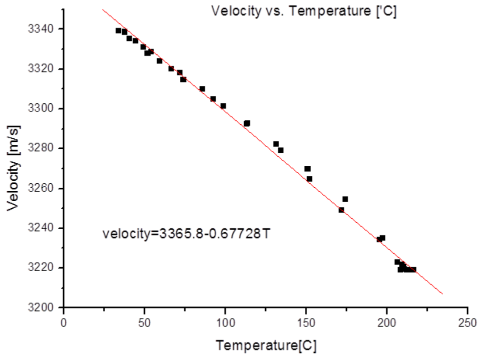


Fig. 4 Calibration of shear wave velocity with temperature of the carbon steel SA 106.

Based on the flight time data and the calibration relation between the shear wave velocity and temperature, the wall thickness is determined at the designated temperature and displayed periodically.

Fig. 4 shows the measurement error during a temperature variation. The nominal wall thickness of the pipe is 7.0 mm. Measurement error can be estimated as ± 10 μm during a cycle from room temperature to 250˚ C.

All information on the high temperature ultrasonic thickness monitoring system can be displayed on the PC monitor, shown in Fig. 6. The right half of the display shows the ultrasonic signal including the gate setting and various parameters for the data acquisition. The left half of the display shows information on the thickness measurement, including date and time, ultrasonic flight time, temperature, thickness determined, and variation of thickness.

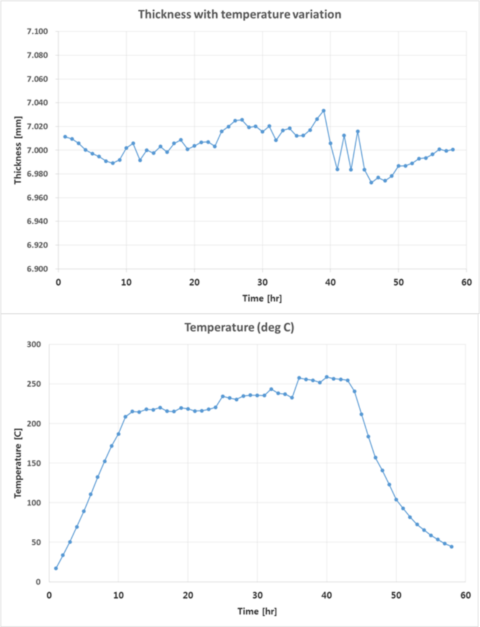
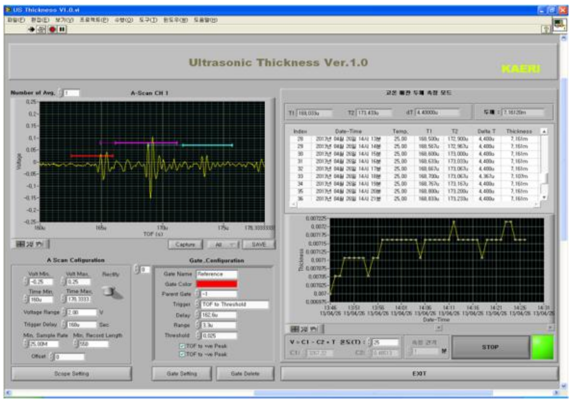


Fig. 5 Measurement error with temperature variation. Thickness variation (top) and temperature variation (bottom)



Number of Avg. 1

T1 168.033u T2 173.433u dT 4.40000u 두께 : 7.16120m

Index	Date-Time	Temp.	T1	T2	Delta T	Thickness
28	2013년 04월 26일 14시 13분	25.00	168.500u	172.900u	4.400u	7.161m
29	2013년 04월 26일 14시 14분	25.00	168.567u	172.967u	4.400u	7.161m
30	2013년 04월 26일 14시 15분	25.00	168.600u	173.000u	4.400u	7.161m
31	2013년 04월 26일 14시 16분	25.00	168.633u	173.033u	4.400u	7.161m
32	2013년 04월 26일 14시 17분	25.00	168.667u	173.067u	4.400u	7.161m
33	2013년 04월 26일 14시 18분	25.00	168.700u	173.067u	4.367u	7.103m
34	2013년 04월 26일 14시 19분	25.00	168.767u	173.167u	4.400u	7.161m
35	2013년 04월 26일 14시 20분	25.00	168.800u	173.200u	4.400u	7.161m
36	2013년 04월 26일 14시 21분	25.00	168.833u	173.233u	4.400u	7.161m

Volt Min. -0.25
Volt Max. 0.25
Time Min. 160u
Time Max. 178.3333
Voltage Range 2.00 V
Trigger Delay 160u Sec
Min. Sample Rate 25.00M
Min. Record Length 550
Offset 0

Gate Name Reference
Parent Gate -1
Trigger TOF to Threshold
Delay 162.6u
Range 3.3u
Threshold 0.025
☑ TOF to +ve Peak
☑ TOF to -ve Peak

V = C1 - C2 * T 온도(T) : 25

Fig. 6 An example of PC display for data acquisition and monitoring

3. Conclusions

Ultrasonic wall thickness measurement/monitoring system for high temperature pipe thinning is developed. The pitch-catch method was used with two shear horizontal waveguides. A clamping device for dry coupling contact between the end of waveguide and pipe surface is developed. The configuration of the ultrasonic transducer with its face on the cross section of the strip and pitch-catch mode on the clamped to the plate shows a high signal amplitude and S/N ratio.

A computer program for on-line monitoring of the pipe thickness at high temperature for a long time period was developed. The system can be applied to monitor the FAC in carbon steel piping in a nuclear power plant after a verification test for a long period of time. Measurement errors can be estimated as ± 10 μm during a cycle from room temperature to 250° C. The experiment on the wall thickness monitoring at a high temperature will be carried out before installation to the actual piping mockup.

Acknowledgement

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REFERENCES

[1] Yong-Moo Cheong, Ha-Nam Kim, and Hong-Pyo Kim, “Ultrasonic Thickness Monitoring Using a Shear Horizontal Mode Waveguide”, KSNT Spring Conf., May 2012.

[2] Yong-Moo Cheong, Ha-Nam Kim, and Hong-Pyo Kim, “An Ultrasonic Waveguide Technique for On-Line Monitoring of the High Temperature Pipe Thinning”, KSNT Spring Conf., May 2013.