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Implementation of a Multi-channel Ultrasonic Thickness Monitoring Technique for a High Temperature Pipe Thinning

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1. Introduction

Currently pipe thinning has occurred in the carbon steel piping in nuclear power plants. In order to monitor a FAC(Flow Accelerated Corrosion) in a pipe, there is a need to monitor 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, conventional ultrasonic thickness gauging techniques cannot be applied to high temperatures of above 200℃, because conventional 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 addition, 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 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 multi-channel on-line monitoring of the pipe thickness at high temperature was developed. The software is integrated to expand up to 4 channels to monitor several points of the pipe simultaneously, such as an intrados and extrados points at a bent region of a pipe, etc. The system will be implemented to monitor the pipe thinning in a FAC proof facility as well as in nuclear power plant after a verification test for a long period of time.

2. Methods and Results

2.1 Development of a Multi-channel Ultrasonic Thickness Monitoring System

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[2].

A single-channel ultrasonic thickness monitoring system previously developed for laboratory scale[2] was expanded to a multi-channel ultrasonic thickness monitoring system for implementation to the FAC proof test facility. Fig. 1 shows the concept of improvement from a single-channel to multi-channel ultrasonic thickness monitoring system.

A four-channel ultrasonic multiplexer(Model OPMUX 12.0, OPTEL Sp.) and A/D converter with an industrial PC was used. Two shear wave transducers with frequency of 5 MHz are used one for the ultrasonic transmission and the other for ultrasonic reception. 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.

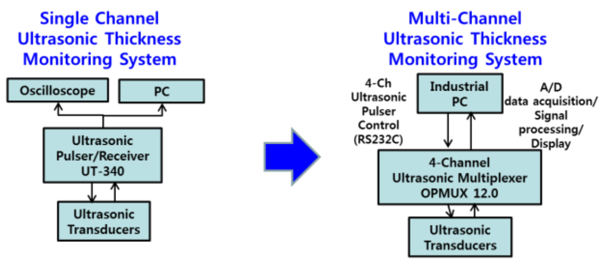

Fig. 1 Concept of Improvement from single-channel to multi-channel ultrasonic thickness monitoring system.

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 ultrasonic rf waveform in the time domain was acquired and processed for the display on the PC screen. Because the ultrasonic rf waveform can be deteriorated at high temperature, acquired ultrasonic signals were optimize to maximized the S/N ratio. Also the system can check the signal quality and designed to show an alarm marker when a unwanted signal was acquired and displayed on the screen.

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. 2).

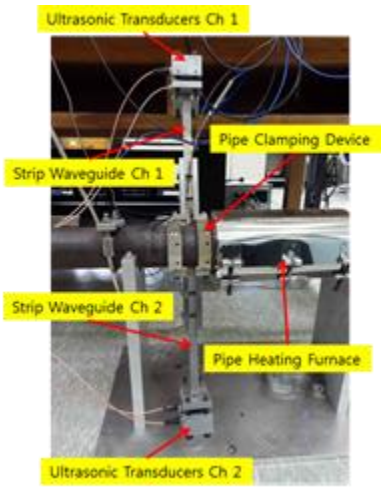

Fig. 2 A pitch-catch waveguide, a clamping device and a test tube with portable furnace.

2.2 Implementation to a FAC Proof Facility

It is required a very accurate calibration reflecting the relationship between the velocity and temperature, because the variation of the ultrasonic wave velocity at high temperature can be a major source of error. Fig 3 shows the relationship between the shear wave velocity and temperature[3].

The flight time between gates was determined at each temperature and converted into the wave velocity. 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.

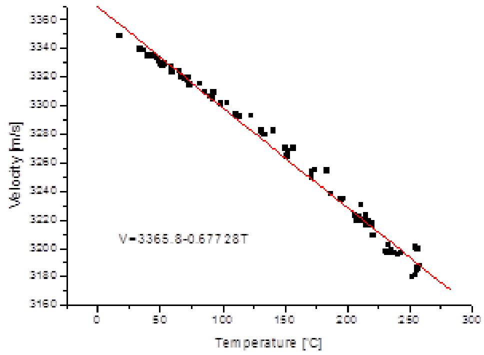

Fig. 3 Calibration of shear wave velocity with temperature of the carbon steel SA 106.

All information on the high temperature ultrasonic thickness monitoring system can be displayed on the PC monitor. The display contains information on the ultrasonic signal acquired in real time, including the gate setting and various parameters. The display also shows the thickness readout with designated time intervals, ultrasonic flight time, and real time temperature reading at the point of measurement. The measurement errors can be estimated as ± 10 μm during a cycle from room temperature to 250˚C after a verification test for a long period of time, shown in Fig. 4.

The system can be implemented to monitor the thickness reduction in carbon steel piping in the FAC proof facility as well as a nuclear power plant. Fig. 5 shows the four-channel ultrasonic transducers are implemented to a test section in the FAC proof facility.

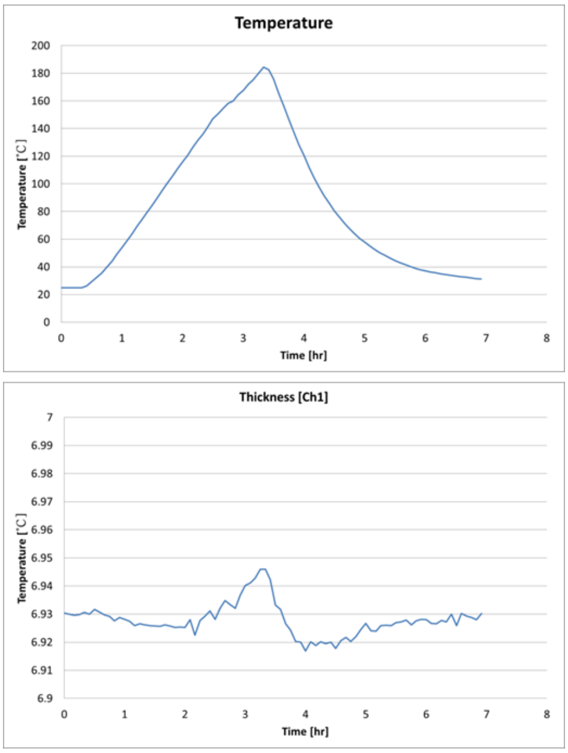

Fig. 4 Measurement error with temperature variation. Thickness variation (top) and temperature variation (bottom).

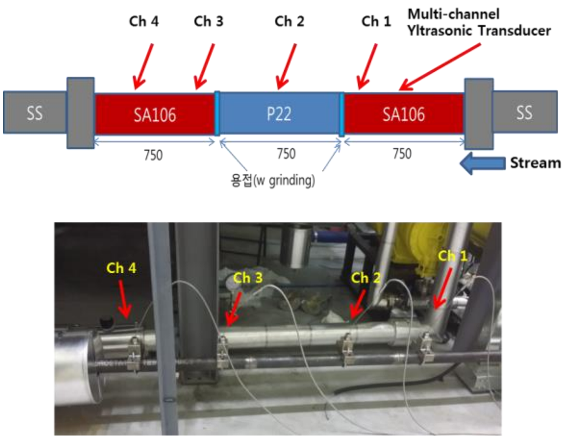

Fig. 5 A four-channel ultrasonic transducers are implemented to a test section in the FAC proof facility.

3. Conclusions

Multi-channel ultrasonic wall thickness monitoring system for pipe thinning at high temperature 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.

A computer program for multi-channel on-line monitoring of the pipe thickness at high temperature was developed. Measurement errors were minimized by a moving gate control with temperature variation, normalization of signal amplitude, automatic determination of ultrasonic flight time, and temperature compensation capabilities. The overall measurement error can be estimated as ± 10 μm during a cycle from room temperature to 250˚C.

The system will be implemented to monitor the pipe thinning in a FAC proof facility as well as in nuclear power plant after a verification test for a long period of time.

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