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Application of High Temperature Ultrasonic Waveguide System for an On-line Monitoring of Pipe Thinning

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1. Introduction

Pipe thinning and leakage due to flow accelerated corrosion (FAC) is one of the important safety concerns of nuclear power plants [1, 2]. Conventional piezoelectric ceramic elements become depolarized at temperatures higher than the Curie temperature, and cannot be applied at temperatures above about 200 ℃. In addition, liquid couplants for the transmission of ultrasonic energy to the test pieces cannot be used at an elevated temperature. Solid couplant should be used for a high quality ultrasonic signals a long time operation at an elevated temperature. However, the differences of thermal expansion coefficients of the test piece, solid couplant and the ultrasonic transducers may cause a failure during the heat cycle operations [3-5].

To solve the problem, we have developed a high temperature ultrasonic thickness monitoring method using a pair of shear horizontal transducers and waveguides [6-8]. We designed and manufactured a high temperature dry clamping device for an acoustic contact between the waveguide and the pipe surface. The high temperature ultrasonic thickness monitoring system shows an excellent S/N ratio and high measurement accuracy with a long exposure times at an elevated temperatures. The system has been successfully implemented in the FAC proof test facility and can be applied to pipe thinning monitoring of nuclear power plants.

2. Methods and Results

2.1 Development of ultrasonic thickness monitoring system with waveguides at high temperature

Because conventional ultrasonic transducers cannot withstand high temperatures, a waveguide type ultrasonic thickness measurement system was developed at an elevated temperature. The transducer system has been installed permanently and allowed frequent acquisitions. It also eliminates an error caused by a variation of examination conditions, such as differences of ultrasonic transducers, ultrasonic equipment, and examination personnel, resulting in very accurate data. In this study, we developed the ultrasonic thickness monitoring system with waveguides at high temperature.

Since the shear horizontal vibration mode used in the waveguide does not show dispersion characteristics, the shear horizontal waveguides and a clamping device were developed. The shear wave transducer was attached to the edge of the waveguide and the specimen attached to on the opposite side to excite and receive the shear horizontal mode. It was ensured that the polarization direction of the transducer was parallel to the width of the strip. As shown in Fig. 1, a clamping device was made capable of attaching two parallel strip waveguides with 1 mm spacing to the plate.

The signal amplitude from pitch-catch type ultrasonic transducers 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 specimen, which reduces their amplitude but avoids pollution from unwanted strip modes that are excited upon reflection from the strip end. It can be seen that signal clarity and transmission through joints without significant distortion are much more important than transmitted amplitude.

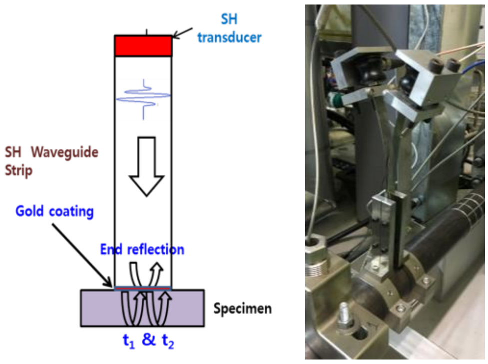

Fig. 1. Design of a pair of waveguides for a high temperature thickness monitoring(left) and an assembly of a pitch-catch type ultrasonic transducers with waveguides(right).

2.2 High temperature pipe thinning online-monitoring system

In order to measure the flight time of the reflected echoes automatically, the 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 automatically determined as the flight time, denoted as

t_1 and t_2 in Fig. 2. We developed a computing algorithm and implemented for an accurate determination of the peak position automatically.

There is no main bang signal in the pitch-catch mode and the signal from the end of the transmission waveguide is very weak, the multiple reflections from the pipe back wall show a clear and high S/N ratio. The signal at the end of the transmission waveguide can be characterized by acoustical contact between the waveguide and pipe. The shear wave velocity of the carbon steel is approximately 3,250 m/s, and the flight time between the first back wall and the second back wall of the 6 mm thick plate is estimated to be 3.7 μsec [9].

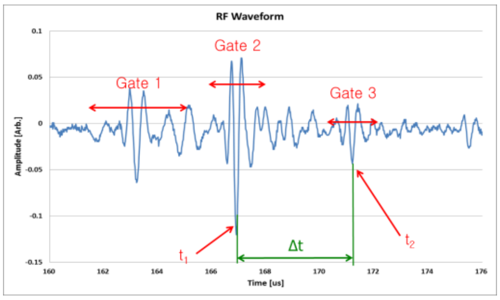

Fig. 2. Typical ultrasonic rf signals at 150℃. The signal acquired by a SH mode waveguide with pitch-catch method. It shows low amplitude of end-reflection and very high amplitude signal from the back-wall.

2.3 Verification in a FAC Proof Test Facility

The carbon steel pipe made of SA106 Gr. B was used for the verification. The dimension of the pipe is outer diameter of 60.4 mm, nominal thickness of 5.54 mm, and length of 750 mm. The pipe wall thickness monitoring data acquired for approximately 3300 hours of operation at an elevated temperature is shown in Fig. 3. The water temperature inside the pipe was maintained at 150 ℃, but at the pipe surface it was measured at about 130 ℃.

The wall thickness reduction during the proof test period was about 300 μm with the measurement error less than ±10 μm. The test period was divided into three phases and the water velocity flowing inside the pipe was varied at each phase, such as the water velocity of 10, 12 and 7 m/s, respectively. The faster the water velocity, the more the wall thickness decreased.

It has been shown that the on-line high temperature pipe wall thinning monitoring system has been successfully implemented in the FAC proof test facility.

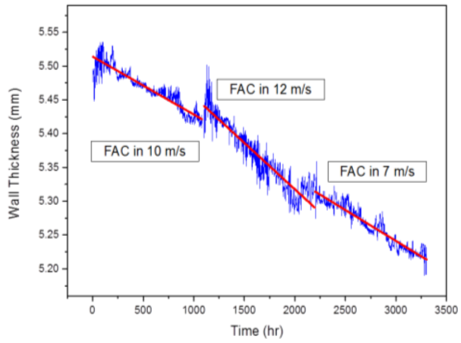

Fig. 3. A pipe wall-thickness monitoring data acquired from a long term operation of the FAC proof test facility: the pipe wall thickness reduction determined by a shear horizontal ultrasonic waveguide pitch-catch technique.

3. Conclusions

A shear horizontal ultrasonic pitch-catch waveguide technique was developed for an accurate pipe wall-thickness monitoring in the FAC proof test facility. A clamping device for dry coupling between the end of waveguide and pipe surface is developed. A computer program for an on-line monitoring of the pipe thinning at an elevated temperature was developed.

The high temperature ultrasonic thickness monitoring system was successfully installed at the test section of FAC proof test facility. The system verified a stable operation at the temperature cycling up to 150 ℃ for several months and the overall measurement error can be estimated lower than ±10 μm. The system can be applied to high temperature thickness monitoring in any industrial application as well as in nuclear power plants.

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