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A Study on Advanced Ultrasonic Technique for Thermal Fatigue Crack Detection of Thermal Stratification Pipeline in NPPs

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1. Introduction

Ultrasonic inspection techniques are widely used to ensure the reliable operation and lifetime extension of nuclear power plants. Thermal stratification typically occurs in the surge line or the main feed water lines in nuclear power plants. Thermal stratification is a flow condition in which hotter fluid flows over a colder region of fluid in pipeline as shown in Fig. 1. Since a change in temperature causes a change in the density of the pipe wall, these thermal conditions might lead to increased overall bending stresses in pipelines. In addition, cyclic changes in stratification height cause thermal stress.

This cycling can lead to thermal fatigue crack initiation and crack growth. If thermal fatigue crack grows continuously, the leakage of water or steam will occur and this may cause serious problems on reactor cooling system. Therefore, these cracks must be detected before the crack growth reaches for leakage[1-4].

In this study, an ultrasonic technique was employed for evaluation of thermal fatigue cracks due to thermal stratification in pipelines of nuclear power plants. The angle beam ultrasonic techniques(time-of-flight diffraction(TOFD) and shadow effect method) were used to detect thermal fatigue cracks which grow from the inner surface of the pipeline. The angle beam ultrasonic technique is usually used for the detection of cracks on the inside of the structures.

When ultrasonic waves generated from the angle probe encounters a crack, ultrasonic waves of the shear modes are reflect or transmit from the crack wall. Also ultrasonic waves generated from the angle probe shear modes are diffracted from the tip of the crack, and the shear wave is reflected from the corner of the crack.

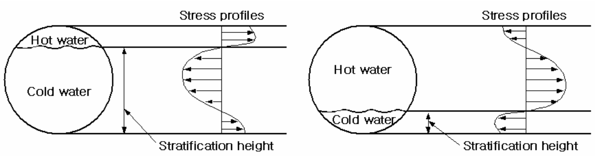


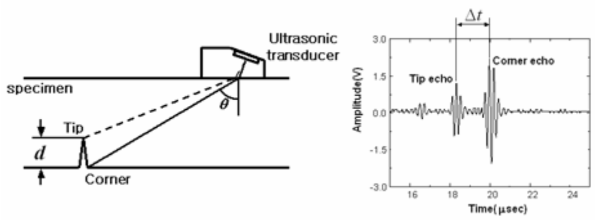
Fig. 1. Thermal stratification in a pipe

2. Methods and Results

2.1 Materials and Experimental Setup

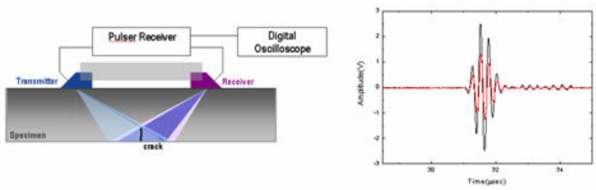
In this study, the angle beam ultrasonic techniques were used to detect thermal fatigue cracks which grow from the inner surface of the pipeline. When ultrasonic waves generated from the angle probe encounters a crack, ultrasonic waves of the shear modes are reflect or transmit from the crack wall as shown in Fig.2. Also we used the shadow effect method to detect closed crack as shown in Fig. 3. This method is application of amplitude decreasing with reflection from crack wall.

The material used in this study was austenitic steel (SUS 304). Four plate typed specimens and one pipe type specimen with different crack size were prepared for evaluation of the crack depth. The thickness of artificial specimens are 4.8, 9.6, 13.1, 19.9 mm and crack depth from 1 to 3mm, respectively. Fatigue cracks were introduced from thermal fatigue testing machine.



(a) The angle beam ultrasonic technique (b) The typical ultrasonic waveform.

Fig. 2 A schematic representation of the angle beam ultrasonic technique(time-of flight diffraction-TOFD)



(a) The angle beam ultrasonic technique (b) Typical waveform comparison

Fig. 3 Schematic diagram of measuring amplitude reduced by shadow effect

2.2 Results and Discussion

2.2.1 TOFD method results

Fig. 4 shows experiment results about artificial crack specimens using TOFD method; thickness 4.8, 9.6, 13.1, 19.9 mm with crack depth from 1.0mm to 3.0mm. From the measurements of arrival times of the diffracted tip echo and reflected corner echo, the depth of a crack tip can be calculated by a simple formula using the time delay between the tip and corner echoes. This technique involves the time measurements only. Therefore, the accurate and reliable results can be easily obtained with slits and open cracks. In case of closed fatigue cracks, however, the problem is not usefulness.

Fig. 5 shows the typical waveform obtained from closed fatigue crack. As shown in Fig. 5, it is difficult to distinguish among diffracted signal from the tip and reflected signal from the corner of the crack because tip signal was very wicked.

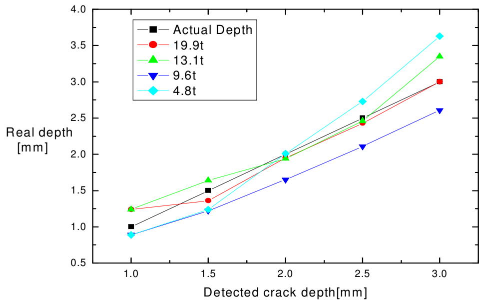


Fig. 4 Experimental results of artificial crack using TOFD method.

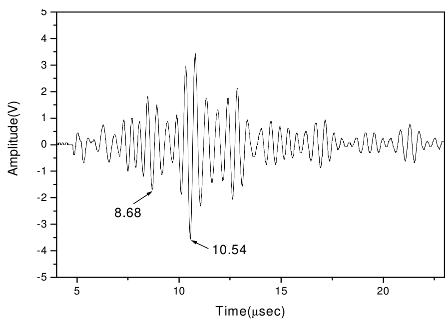


Fig. 5 Typical waveform obtained from closed fatigue crack.

2.2.2 Shadow effect method results

As above mentioned, for sizing of cracks, it is essential to acquire the diffracted tip echo. However, the echo diffracted from the tip of fatigue cracks are usually weak, thus it is not easy to find. Especially, in case of closed cracks, it is hard to acquire the diffracted tip echo because the tip echo is so weak that it may not be distinguished from noise signals. In this reason, we adopted shadow effect methods and observed amplitude decreasing rate by artificial crack depth was quadratic equation curve. Using this quadratic curve equation we detected thickness 7.7 mm fatigued stainless steel pipe specimens with 32,000 thermal cycles. In this case, shadow effect method is very useful to detect close crack such as thermal fatigue crack. However, it is difficult to detected over 3mm crack depth because by amplitude attenuation. Fig. 6 is the experimental results of pipe specimen using shadow effect method. Thermal fatigued crack pipe was fractured to compare detected results and real crack depth section as shown in Fig. 7.

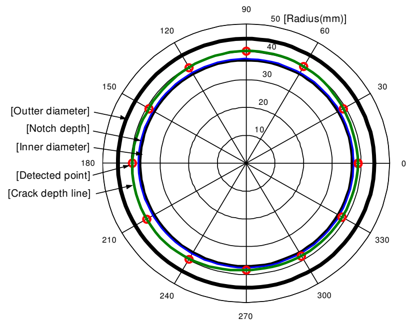


Fig. 6 Plotted results of thermal fatigued crack depth using quadratic curve equation.

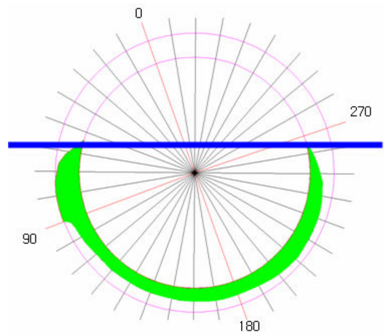


Fig. 7 Plotted results of fracture section of thermal fatigued pipe.

3. Conclusion

In this study, the depths of thermal fatigue cracks were estimated using the angle beam ultrasonic technique. However, it was difficult to evaluate the crack depths accurately using time of flight method only because of the complicated signals of the diffracted tip echo and background noise signals. Therefore, we used to shadow effect method and it confirmed that shadow effect method is very useful to detect close crack such as thermal fatigue crack.

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