ABSTRACT

Ultrasonic testing (UT) is widely applied for the inspection to various plants and structures. However, in the application to the inspection of high attenuation materials such as austenitic weld joints and the inspection near the surface, the SNR (Signal-to-Noise Ratio) decreases and it makes it difficult to assess the testing results.

To solve this issue, systems of a signal processing by the wavelet transform have been developed. Some verification tests for the specimen with austenitic weld joints were conducted. It is confirmed that the extraction of specific frequency components and processing them could help SNR improve and the assessment of the test results.

As for the thickness measurement of thermal sprayed coatings, another system, which is able to apply the discrete wavelet transform to ultrasonic signals, was developed and the field application has been started. The result of the verification tests for austenitic weld joints and the field application of the thickness measurement of thermal sprayed coatings will be presented.

INTRODUCTION

Ultrasonic testing (UT) has been applied to various structures and the in-service inspection of the plants. However, the testing for the coarse grained material such as austenitic weld joints or the inspection near the surface, the signal-to-noise ratio (SNR) becomes lower than the testing for conventional testing. Also there is a growing need for the detection of the minute flaws those were difficult to detect by conventional UT. To solve these issues, signal processing methods including FFT and filtering processing have been studied. The signal processing used to be done after the data acquisition. Recent computers’ speedup helps the simultaneous signal processing.

UT apparatuses with signal processing by the wavelet transform have been developed. Examinations for the specimen with austenitic weld joints were conducted. It is confirmed that the extraction of specific frequency components could help SNR improve and the understanding of the test results. As for the thickness measurement of thermal sprayed coatings, another apparatus, which is able to apply the discrete wavelet transform to ultrasonic signals, was developed and the field application has been started.

WAVELET TRANSFORM

The Fourier transform, which provides transformed signals into the frequency domain, has been commonly applied to the signal processing for various purposes. However, the time axis information in signals is lost by this transform, as is well known. To solve this issue, the wavelet analysis has been developed [1-3] and applied to the signal processing for the nondestructive testing [4-6].

The wavelet transform is like a filter, which extracts frequency components from the signals without losing time axis information. Fig. 1 shows an example of the mother wavelet. By scaling and translating the mother wavelet, similar components to the mother wavelet can be obtained from the signals. By this signal processing, it should be possible to separate and reduce noise found in raw ultrasonic signals.

In addition, due to the development of the algorithms, the calculation can be speeded up. Fig. 2 shows the comparison result of calculation. Calculation after transforming the ultrasonic signals into frequency domain becomes faster than the conventional calculation (in time domain) and it comes true the real-time processing.
APPLICATION TO ULTRASONIC TOFD METHODS

Cracks in thickness direction and lack of fusion on the groove face are harmful for the weld joints, and it is necessary to accurately detect such flaws non-destructively to secure high structural integrity. Especially, to evaluate flaws in fracture mechanics, it is important to correctly measure the size in the thickness direction. The ultrasonic TOFD method was developed in the U.K. in 1980 and has been a useful technique for dimensional measurement of flaws. This method is partially used for the in-service inspection of the pressurized boiler components and pressure vessels. In this examination, TOFD method was employed for data acquisition.

![Daubechies Wavelet of order 10](image1.png)

**Figure 1 - Daubechies Wavelet of order 10**

![Comparison of calculation time](image2.png)

**Figure 2 - Comparison of calculation time**

**Test results of 9% Ni steel weld specimen**

9% Ni steel is used for inner tanks of the LNG storage facilities and the filler metal used is nickel based materials. Therefore, the weld metal becomes austenitic and grass can be observed in the ultrasonic signals due to development of dendrites. The grass makes it difficult to recognize the flaw indications.

The specimen, 50mm-thick 9% Ni steel weld joints with the hot cracks, were prepared and testing by ultrasonic TOFD method was conducted. Ultrasonic transducers used were broadband of
2.25MHz, the element size was 12.7mm in diameter. The incident angle and the distance between transducers were set 50 degree and 70mm, respectively. The scanning of the transducers was parallel to the weld joint (i.e. D-scan) and the scan increment was set 1mm.

Fig. 3(a) shows D-scan image of the raw ultrasonic data. The hot cracks location in thickness direction was 10mm from the back-wall. The lateral wave and back-wall reflection were observed in Fig. 3 (a). Also flaw indication and grass were observed between them. Fig. 3 (b) shows the continuous wavelet transform (CWT) result of the signal at 160mm in the D-scan image. The flaw indication has the frequency components between 1 and 5 MHz. Meanwhile, the grass has the components between 2 and 5 MHz. Fig. 3 (c) shows the D-scan image of 1.0MHz frequency components. Arrows show the flaw indications.

Test results of SCC specimen

Type 316 stainless steel weld joint with a SCC was employed as the specimen (35mm-thick). At the edge of the specimen, the crack height was found to be 13mm from the back-wall. Fig. 4 shows the B-scan image near the edge. Fig. 4 (a) shows an image by raw ultrasonic data and Fig. 4 (b) shows the B-scan image of the 1.7MHz frequency components after CWT. The height of the SCC measured from Fig. 4 (b) was 14mm from the back-wall.

Figure 3 - Test results for 9%Ni steel weld specimen: (a) D-scan image of raw data, (b) wavelet transform result and (c) D-scan image of extracted data (1.0MHz)

Figure 4 - Test results for weld specimen with SCC: (a) B-scan image of raw data and (b) B-scan image of extracted data (1.7MHz)
THICKNESS MEASUREMENT OF THERMAL SPRAYED COATINGS

Because of the diversification of boiler structure and fuel, thermal sprayed coatings are presently being applied to surfaces of boiler components to prevent erosion and/or corrosion [7]. Methods for the nondestructive evaluation of degradation and damage, such as decrease in coating thickness should thus be made available for maintenance and quality assurance.

Usually, an electromagnetic thickness meter can be used for a particular non-magnetic coating thickness measurement when the substrate is magnetic. However, in the case of magnetic coatings, an electromagnetic thickness meter is not suitable for measuring thicknesses.

In CFB (Circulating Fluidized Bed) boilers, the heat exchanger tube was installed in the fluidized bed. Erosion due to the collision of the bed material has thus been concerned. This chapter describes the coating thickness measurement technique and the application at the field.

Ultrasonic coating thickness measurement technique

The electromagnetic thickness meters determine the coating thickness based on the liftoff between the sensor and magnetic substrate. For the magnetic coating, it is quite difficult to measure the precise liftoff because of the magnetism of the coating.

The coating is generally thin (~1mm) and porous. It is hard to determine the reflection from the boundary between coatings and substrates when applying the conventional UT. The thickness measurement technique by ultrasounds was developed in IHI Corporation [8]. A twin-crystal, longitudinal wave probe, which has a frequency broadband of 10MHz, was used and a contact method from the coating surfaces using the normal beam technique was applied. The discrete wavelet transform was applied to the acquired data to extract the specific frequency components.

Ultrasonic signals for measuring coating thickness

17Cr-Fe spraying, Fe-based materials, has been employed the heat exchange tube in CFB boilers for the protection from erosion. The measurement by ultrasounds should be able to provide accurate thicknesses compared to electromagnetic thickness meters. Fig. 5 shows the raw ultrasonic signals and the extracted signals (less than 6.3MHz) after discrete wavelet transform.

Figure 5 - Example of signal analysis (a) raw data and (b) extracted data of a specific frequency band
Application of real-time signal processing under field condition

LeCroy Waverunner 44Xi, controllable on WinXP, was used as the oscilloscope and the program was developed by MATLAB. Fig. 6 (a) shows a block diagram of the developed apparatus. This apparatus enables the sequence of the measurement; data acquisition, signal processing and thickness determination.

Fig. 6 (b) shows an example of front panel of the apparatus. When the acquisition was stopped, the last raw data and its processed data remained on the front panel. The peak echo time is able to read off by a cursor and the coating thickness is determined from parameters of the standard curve (correlation between the peak echo time and coating thickness).

The measurement under the field has started by this apparatus. Fig. 7 shows the measurement under field condition. The thickness used to be determined after all data acquisition. This apparatus provides the real-time thickness determination and improvement of reliability of the measurement as well.

Figure 6 - (a) Block diagram and (b) front panel of the apparatus

Figure 7 - Measurement under field conditions

SUMMARY

This presentation introduced real-time signal processing for ultrasonic signals. Apparatus of real-time wavelet transform for ultrasonic test data were developed. The examinations of the ultrasonic
TOFD method for austenitic weld joints were conducted and it is confirmed that extracting specific frequency components after CWT provides SNR improvement of the D-scan image. As for the coating thickness measurement, the apparatus, which is able to perform data acquisition, processing and thickness determination simultaneously, were established and the field application has been started.

For future work, the development of more user-friendly apparatuses, especially further downsizing and portability, should be considered. This technique and apparatus would provide more efficient inspection and help understanding the test results in the field measurements.

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