Flaw Detection using Electromagnetic Acoustic Resonance for a Tube of NPP

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1. Introduction

In order to ensure integrity of power plants, tube inspection is conducted periodically. But it is difficult to obtain access for inspection because of the condition of tube installation and radiation environment. Especially in situations where access is restricted, tube inspection in circumferential direction is impossible. For this reason, we propose an electromagnetic acoustic resonance technique for detection of defects on the opposite side of the tube of interest.

In this paper, we present preliminary experimental verification of the proposed method and show that the defects on steel tubes can be detected based on changes in resonant frequencies.

2. Methods and Results

2.1 Electromagnetic acoustic resonance

The electromagnetic acoustic resonance technique involves excitation of the circumferential resonance of a tube, detection of the resulting resonance vibration signals, use of these signals to measure the resonant frequencies of the tube, and detection of flaws based on changes in resonant frequencies.

To generate acoustic resonance along the circumferential direction of a tube, we used the SH-wave mode with the magneto-strictive sensor (MsS).

The concept of defect detection is illustrated in Fig. 1. In case there is no defect as shown in Fig. 1a, the MsS directly receives the acoustic resonance wave. However, in case there is a defect as shown in Fig. 1b, the wave reflected by the defect should travel a shorter distance. Since it can be assumed that the change in distance traveled in a tube occurs due to a defect, the resonant frequency (f_{re}) can be calculated as follows:

$$f_{re} = \left(f_{\text{int act}} + f_{defect}\right)\cdot 2^{-1} = \left(\frac{C_{\text{int act}}}{\lambda_{\text{int act}}} + \frac{C_{defect}}{\lambda_{defect}}\right)\cdot 2^{-1} \qquad (1)$$

$$\lambda_{\text{int act}} = n\cdot L\,,\ n = 1,2,3.... \qquad (2)$$

$$\lambda_{defect} = n\cdot(L-\Delta L) = n\cdot L'\,,\ n = 1,2,3.... \qquad (3)$$

where $C_{\text{int act}}$ and C_{defect} are wave velocities in a tube without a defect and with a defect, respectively and $\lambda_{\text{int act}}$ and λ_{defect} are wavelengths of excitation frequency generating acoustic resonance and n is the order of resonant frequency.

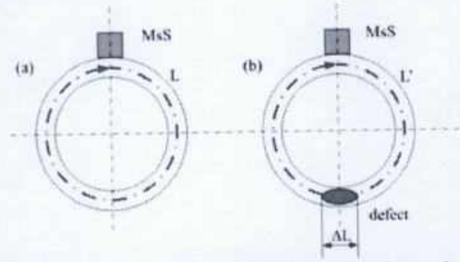

Fig. 1. Concept of defect detection based on changes in resonant frequencies: (a) intact (b) defect

2.2 Specimens

Fig. 2 and Table 1 show the shape of test specimens and specifications. Tube material is 13CrMo44, the outer diameter is 38 mm, thickness is 5.6 mm, length is 950 mm, length of defects is 30 mm, 50 mm, 100 mm, and 300 mm, and depth of defects is 2.8 mm and 5.6 mm.

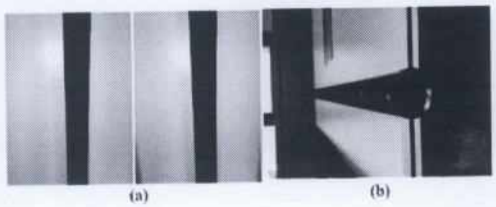

Fig. 2. The shape of various defects and specimens

Table.1. Defect-size specification

No.	Shape	Length of defects [mm]	Width of defects [mm]	Depth of defects [mm]
RS#1	Notch	300/100	1	4.2
RS#2	Notch	300/100	3	4.2
RS#3	Notch	300/100	5	4.2
RS#4	Notch	100/50/30	1	4.2
RS#5	Wall loss	300/100	50.9	2.8

2.3 Test equipment

The acoustic resonance inspection system (ARIS) was used in order to generate and receive the acoustic vibration signals. The ARIS includes MsS that utilizes magnetostrictive effects and ARIS software that provides the user with overall control of the ARIS. The sensor is excited by a tone-burst of given frequencies and detects circumferential SH-wave resonance vibrations, but it does not come in contact with the surface of the tubes. Fig.3 shows details of this system.

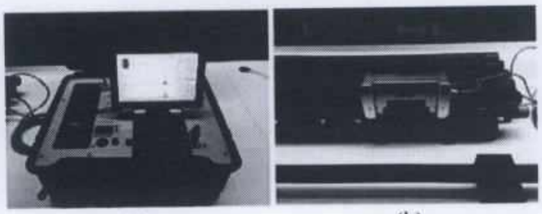

Fig. 3. (a) ARIS for tube inspection and (b) MsS

2.4 Experimental methods

MsS was installed at the end of the tube specimens. Their frequency range was from 100 kHz to 200 kHz. Acoustic vibration signals were collected by using the pulse-echo method. Then, this data was compared for analysis.

2.5 Signal characteristics according to the type of defects

As shown in Fig. 4, the signals obtained in a tube without a defect well demonstrate an acoustic resonance characteristic. Fig. 4a shows signals filtered with butterworth filter at all frequencies. Fig. 4b shows FFT results and 4^{th} to 6^{th} resonant frequencies. Table 2 shows the calculated resonant frequencies and the measured resonant frequencies.

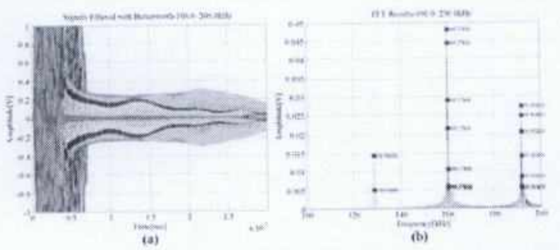

Fig. 4. Experimental result of a tube specimen without a defect: (a) signals filtered with butterworth filter and (b) FFT results

Table.2. Resonant frequencies of a tube specimen without a defect

The order of resonant frequency	4^{th}	5^{th}	6^{th}
Calculated resonant frequency [kHz]	126.93	158.66	190.39
Measured resonant frequency [kHz]	128.56	160.37	191.81

As shown in Fig. 5, FFT results show a change in resonant frequency according to the defect. Fig. 5a and Fig. 5b show resonant frequencies obtained at the location without a defect and with a defect, respectively. From these results, it can be seen that all of the resonant frequencies are moved up. This is due to the combination of resonant frequencies caused by the wave passing by the defect and reflected from the defect. On the other hand, the resonant frequency increases depending on the width of the defect because the propagation distance of the SH-wave is reduced.

Consequently, the defect on the opposite side of the tube can be detected based on changes in resonant frequency as shown in Fig. 5b. Table 3 shows changes in measured resonant frequencies due to the defect of 300 mm length.

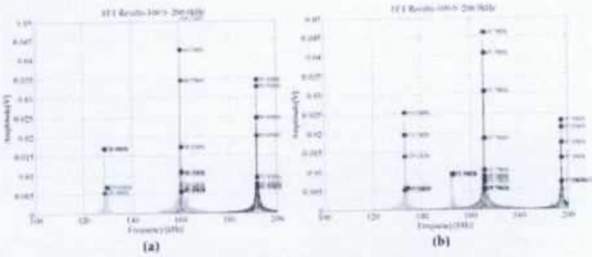

Fig. 5. Experimental result of a tube specimen RS#3: (a) without a defect and (b) with a defect

Table.3. Resonant frequencies of a tube specimen RS#3 with a defect

The order of resonant frequency	4^{th}	5^{th}	6^{th}
No defect [kHz]	128.56	160.37	191.81
Notch [kHz]	133.21	165.79	197.30
Difference [kHz]	4.65	5.42	5.49

3. Conclusions

In this paper, preliminary experimental verification of the proposed method to detect the notch in steel tubes was conducted by using the acoustic resonance inspection system.

The results of this study showed that:

1) The electromagnetic acoustic resonance technique can detect notch defects on the tube.
2) The changes in resonant frequencies are approximately proportional to the width of defect.

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