Application of pipe thinning caused FAC measurement technology using magnetostrictive strip guided ultrasonic non-destructive inspection

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1. Introduction

In the secondary system of a nuclear power plant, pipe thinning due to flow accelerated corrosion (FAC) caused a rupture accident, resulting in economic loss and human injury [1-4]. Many of these cases have already been revealed, and the importance of inspection to prevent accidents cannot be overemphasized. However, the pipeline of the nuclear power plant is not only structurally complicated, but it is located in the high radioactivity area and covered with heat-insulating materials, so it is difficult to apply conventional pulse-echo ultrasonic nondestructive inspection technology [5].

For the inspection of such pipes, the guided ultrasonic method is widely used. Currently, the commercially available guided ultrasonic wave method for pipeline inspection includes an array-type piezoelectric ceramic method and a magnetostrictive technique. In order to generate a torsional vibration mode using a piezoelectric element, dozens of array-type piezoelectric sensors are required, resulting in increased cost, complicated design, and difficult to guarantee performance [5]. To solve this problem, magnetostrictive strip-guided ultrasonic inspection techniques are considered. Magnetostrictive guided wave technique which is a method of transmitting and receiving guided ultrasonic waves by winding a single strip with magnetostriction in the direction of the pipe circumference [5]. As an advantage of guided ultrasonic inspection technology using the magnetostrictive method, scanning is not required, and since ultrasonic waves are little attenuation, a mostly volumetric coverage of long-distance inspection is possible [6]. Also, when this characteristic is used, the structure is very simple in the form of a strip, the cost is low, and the symmetric torsional vibration mode can be easily obtained. In this study, after conducting a demonstration test of pipe thinning using the FAC facility, various thinning-related signals were evaluated using magnetostrictive strip guided ultrasonic technology, and analyzed in terms of electromagnetic properties of pipeline materials and magnetostrictive strip transducers.

2. Methods and Results

2.1 The principle of the magnetostrictive ultrasonic guided wave technique.

When an AC magnetic field is applied to a magnetic material, the material vibrates. This characteristic of changing size according to the magnetic field is called magnetostriction, and this phenomenon is called the Joule effect [7]. On the other hand, if the length of the material is changed within the magnetic field, the Villari effect occurs [8, 9]. As described above, by utilizing the relationship between the magnetic field and the deformation of the material, ultrasonic waves can be generated and a signal can be detected, so various applications are possible. In order to generate guided ultrasonic waves in the axial direction in the torsional vibration mode, a ferromagnetic strip with excellent magnetic transformation characteristics, such as Fe-Co-V alloy, is wound in the circumferential direction of the pipe using epoxy adhesive [6]. After that, a DC bias magnetization state must be formed in the circumferential direction. Two coils with a distance of 1/4 wavelength are wound around a bias magnetized strip to control the direction of wave propagation. Magnetization is induced in the magnetostrictive strip by rotating the permanent magnet in the circumferential direction of the magnetostrictive strip to form a DC bias magnetization. The shear displacement generated in the magnetostrictive strip is transmitted to the pipe through the epoxy bonding, so that the torsional vibration T(0,1) mode propagates along the pipeline [7]. Among the various vibration modes of the guided ultrasonic dispersion diagram, the torsional vibration mode in particular has no difference in speed according to the change of frequency. Since there is no dispersion, it is possible to obtain a very sharp signal shape, and physically there is no displacement in the radial direction like the SH (shear horizontal) vibration mode on a flat plate, so there is an advantage that there is little attenuation even when the pipe is filled with water [10].

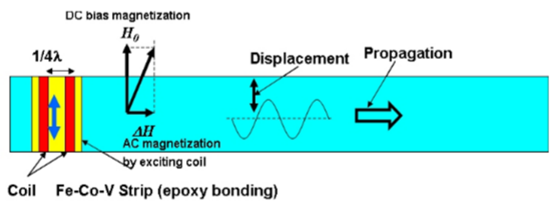


Fig1. Photo of widermann effect [7].

Table 1. Characteristics of magnetostrictive strip guided ultrasound

Consist of transducer	Ni strip or magnet and two coils
Physical principle	Magnetoacoustic effect
Ultrasound rash	Output limited by bias magnetization, tone-burst method
Direction	Adjustable
Vibration mode	T-mode & L(f)-modes
Frequency range	32-256kHz
Field application	Symmetrical sensitivity to the circumferential direction, Epoxy bonding required, Limited power
Test specimen	No limit(L-mode is advantageous for ferromagnetic properties)

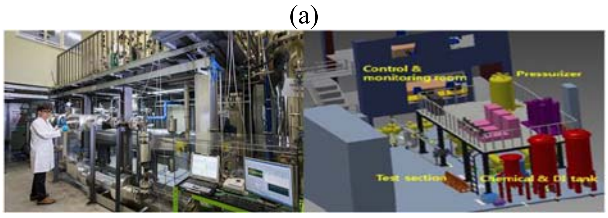
2.2 FAC experiment conditions and measurement of Magnetostrictive strip guided ultrasonic wave.

FAC test section was made of SA106 alloy steel. FAC experiment has been performed using the FAC demonstration test facility (Fig. 2b), which was designed and manufactured by Korea Atomic Energy Research Institute (KAERI) [11]. The test was performed under the conditions of a temperature of 130 °C, DO <5 ppb, pH 6~7, and flow rate of 1.5 m/s (fig. 2c) for 33 d (800 h). The magnetostrictive strip was installed on the straight pipe line before the start of the experiment (Fig. 2a). By generating guided ultrasonic waves using these magnetostrictive strips, it is possible to monitor the thinning condition of the straight pipe line where flow accelerated corrosion during operation of the FAC facility. It is possible to measure the location and amount of thinning by on-line monitoring the change of ultrasonic signals at regular intervals.

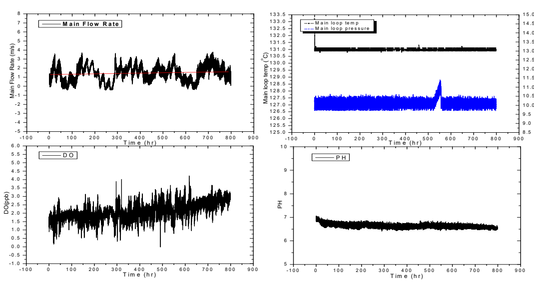
Table 2. Chemical composition of pipe materials (wt%)

Alloy	C	Si	Mn	Cu	Cr	Ni	Mo
SA106 Gr.B	0.19	0.24	0.98	0.02	0.04	0.02	0.01

(a)



(b)

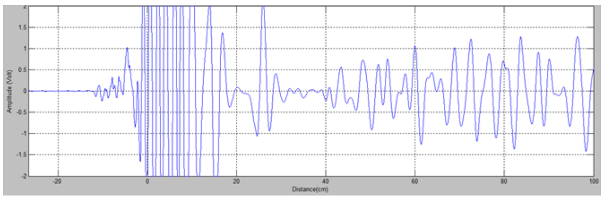


(c)

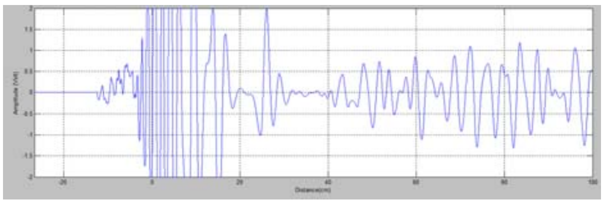
Fig. 2. (a) Photo of FAC test section and magnetostrictive strip installation, (b) Photo of FAC demonstration test facility, (c) test conditions of this experiment.

2.3 Signal measurement analysis.

First, each signal was checked by referring to the structural characteristics of the pipe. To do this, we analyzed the waveform amplitude and phase of each ultrasonic signal and correlated it with the actually relevant signal. Fig. 3a shows the received ultrasonic wave signal of the straight pipe before FAC operation, and fig. 3b shows the received ultrasonic wave signal of the straight pipe after FAC operation. Fig. 3c shows the received signals of Fig. 3a and 3b superimposed. Since the guided ultrasonic signals before and after operation contain information on the integrity of the pipe at the time of measurement, the difference between these signals can show the change in the state of the pipe according to the FAC operation. Fig. 3d shows the difference in the signal before and after FAC operation, and the change in the pipe can be detected from this signal. The amplitude of the ultrasonic signal received was changed at the point where the corrosion defect occurs. Through this method, it is possible to diagnose whether the pipeline is damaged in advance and prevent to the pipeline breakage accident.



(a)



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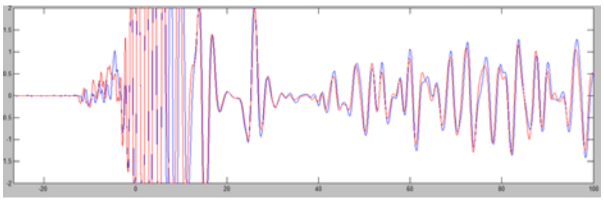
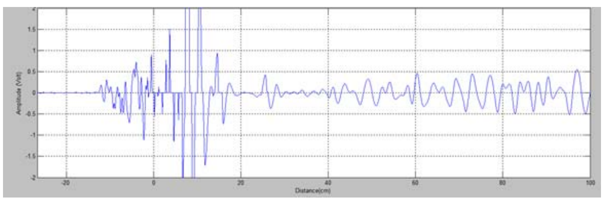


(c)



(d)

Fig. 3. (a) Guided ultrasonic reception signal before FAC operation, (b) Guided ultrasonic reception signal after FAC operation, (c) Guided ultrasonic reception signal before and after FAC operation (before FAC operation: blue, after FAC operation: red), (d) Differences in the received signal of Guided ultrasonic waves before and after FAC operation.

3. Conclusions

In this paper, when applying magnetostrictive strip guided ultrasonic inspection technology to pipe thinning measurement, the most important matters are the selection of suitable vibration mode and selection of specific oscillation/reception sensors. The torsional vibration mode has many advantages because it has no mode conversion and dispersion, and is relatively less affected by the external matter. Using these advantages, a magnetostrictive strip guided ultrasonic sensor was installed in the pipe to enable constant monitoring through the periodic signal collection. By doing so, it was possible to estimate where the pipe thinning occurred. In the future, this technology will be able to contribute to the reduction of cost and time in improving the safety and quality control of facilities such as nuclear power plants.

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