AFI-2019
November 6-8, 2019, Sendai, Miyagi, Japan

OS20-12

Back Surface Roughness Measurement Based on Attenuation of Ultrasonic Wave

Hiroyuki Nakamoto[1], Philippe Guy[2], Toshiyuki Takagi[3, 4], Tetsuya Uchimoto[3, 4], Kazuya Hamaguchi[5]
[1]Graduate School of System Informatics, Kobe University, 1-1 Rokkodai, Nada-ku, Kobe, Hyogo, 657-8501, Japan
[2]Laboratoire Vibrations Acoustique, INSA de Lyon, Avenue Jean Capelle, 69621 Villeurbanne Cedex, Lyon, France
[3]Institute of Fluid Science, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi, 980-8577, Japan
[4]ELyTMaX UMI 3757, CNRS–Université de Lyon–Tohoku University,
International Joint Unit, Tohoku University,Sendai, 980-8577, Japan
[5]Hyogo Prefectural Institute of Technology, 3-1-12 Yukihira, Suma-ku, Kobe, Hyogo, 654-0037, Japan

ABSTRACT

This study aims to measure the inner surface roughness of pipes. A proposed method separates the reflected wave to multiple waves with different frequencies by bandpass filters. Then, the method calculates multiple attenuation variables from the waves. This paper compares experimental attenuation variables with theoretical curves to confirm the potential of the separation method.

1. Introduction

A piping network in nuclear power plants is one of the important components to maintain the health of the plant. Corrosion in the pipe causes a severe accident such as the burst of the pipe. Hence, measurement devices should monitor and detect corrosion. In corrosion monitoring, inspectors mainly measure the pipe wall thickness. However, the inner surface of the pipe is not smooth and has roughness. Poulson reviewed the development of roughness due to flow accelerated corrosion (FAC) and its effect on mass transfer [1]. Kain reviewed the forms and mechanisms of FAC [2]. From these reports, thickness measurement is not enough to monitor the partial degradation of the pipe. The monitoring of both the thickness and roughness seems effective for evaluation of the pipe.

An inspector measures pipe-wall thickness by an ultrasonic transducer. The pulse-echo method determines the thickness from the time of flight of the ultrasonic wave and its velocity. On the other hand, Nagy et al. derived an attenuation equation of reflected and transmitted ultrasonic waves due to the rough surface [3]. Ogilvy modeled a reflected wave from rough defects inner an object [4]. These models indicate that the back surface roughness of the pipe can be measured from the reflected ultrasonic wave in theory. A practical measurement method is required to measure the roughness of pipes in an inspection.

This study proposes a measurement method of the inner surface roughness of pipes. The proposed method separates the reflected wave to multiple waves with different frequencies by bandpass filters. The method calculates multiple roughnesses from the waves and finally averages them. This paper compares experimental attenuation variables with theoretical curves.

2. Method

We consider a reflection of an ultrasonic wave and assume that the back surface is rough. The rough back surface scatters the ultrasonic wave as shown in Fig.1. In a general manner, we will assume that the attenuation is given by a decreasing exponential law as follows:

$$r = r_0 e^{-f(h)} \tag{1}$$

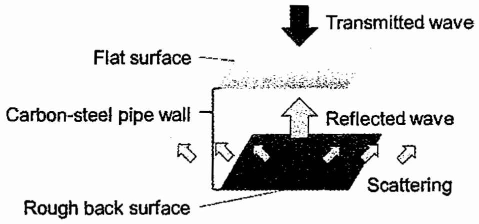


Fig. 1 Transmitted wave and reflected wave from rough back surface.

where r_0 and r are the amplitude reflection coefficients at the flat and rough back surfaces, respectively, and $f(h)$ is an attenuation function to be determined in relation with the roughness parameter h. h is a root-mean-squared value of the surface.

Let us consider the reflections at the flat and rough back surfaces. The flat back sample is for the reference sample. If we obtain the first and second reflections from the back surface, the following equation is derived [5].

$$\frac{\frac{R^{2nd}}{R^{1st}}}{\frac{R_0^{2nd}}{R_0^{1st}}} \approx \frac{r}{r_0} = e^{-f(h)}, \tag{2}$$

where R_0^{1st}, R_0^{2nd}, R^{1st} and R^{2nd} are the first and second reflections from the flat and rough back surfaces, respectively. Hence, we define an attenuation variable:

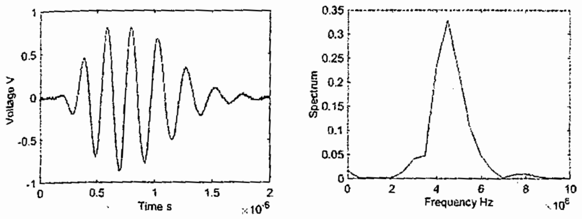
$$\beta = \ln\left(\frac{\frac{R^{2nd}}{R^{1st}}}{\frac{R_0^{2nd}}{R_0^{1st}}}\right) = -f(h). \tag{3}$$

In regard to the attenuation function $f(h)$, Nagy et al. derived the following equation [3].

$$f(h) = 2k^2h^2, \tag{4}$$

where k is the wavenumber of the ultrasonic wave. The frequency and velocity of the ultrasonic wave determine the wavenumber. The ultrasonic velocity depends on the material of the pipe. If a probe transmits an ultrasonic wave with a well-focused frequency, we might obtain the roughness with high accuracy based on the equation (4).

Corresponding author: Hiroyuki Nakamoto
E-mail address: nakamoto@panda.kobe-u.ac.jp



(a) Echo from flat surface. (b) FFT spectrum.

Fig. 2 Typical experimental data of reflected wave.

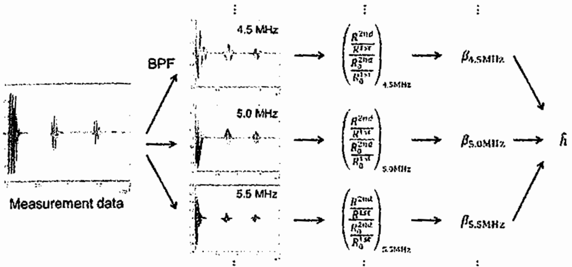


Fig. 3 Schematic of roughness measurement method.

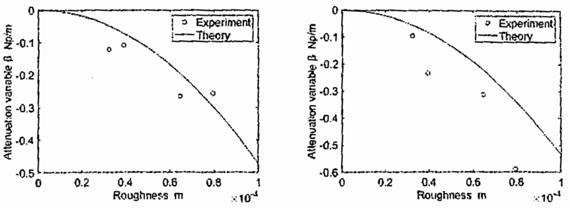
However, an ultrasonic probe generally has a frequency band of a specific width. For example, Fig. 2 (a) and (b) show a typical echo from a flat back surface and its frequency spectrum by a fast Fourier transformation, respectively. Although the ultrasonic wave is excited by a 5-MHz probe, Fig. 2 (b) has a bandwidth in frequency. Hence, the ultrasonic wave includes waves with different frequencies. This result is not along with the assumption which the ultrasonic has a specific frequency shown in equation (4).

To obtain an ultrasonic wave with a well-focused frequency, we separate measurement data into a set of filtered data by bandpass filters (BPFs). A schematic of this separation shows in Fig. 3. The BPFs separate the measurement data into three data with different frequencies. The separated data determine the amplitudes of the first and second echoes from a rough back surface. The parameter β is calculated based on them and the amplitudes of a flat back surface. Finally, a set of β determines the roughness parameter $\hat{h}$.

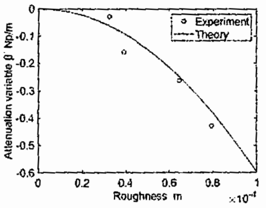
3. Results and Discussion

The experimental instrument was composed of a pulser-receiver device (JPR-600C, Japan Probe Co. LTD) and an L-wave probe (5C10N, 5 MHz, Japan Probe Co. LTD). Specimens were three carbon steel blocks which had 20 mm in thickness and an area of 40×40 mm^2. One for reference data had flat surfaces. The other specimens were given two sets of different periodic flaws, simulating roughness, on one side by a machining process.

In experiments, we obtained echo signals from the flat and rough back surfaces. The bandpass filters (MATLAB R2018a, The MathWorks, Inc.) separated the experimental data into three data with central frequencies of 4.5, 5.0 and 5.5 MHz. We determined the amplitudes of the first and second echoes of the separated data and calculated the attenuation variable β from them. Fig. 4 shows the relationship between β and the attenuation function expressed by equation (4).



(a) 4.5 MHz. (b) 5.0 MHz.



(c) 5.5 MHz.

Fig. 4 Experimental data and theoretical curve.

In Fig. 4, the 4.5-MHz data were not sensitive to roughness and the 5.0-MHz data were very sensitive. The 5.5-MHz data were close to the theoretical curve. The one set of measurement data generated the three data sets. However, their tendencies were different. These results implied that the separated data might include individual information regarding the back surface based on their frequencies. In this experiment, a narrow band probe of 5 MHz obtained the first and second echoes. If a broadband probe obtains data, it is possible to apply bandpass filters with a wide range and to make many separated data.

4. Concluding Remarks

This paper proposed the roughness measurement method with bandpass filters. The experimental attenuation variables showed different tendencies with the frequency of the filter. In the future works, we will reveal the relationship between the separated data measured by a broadband probe.

Acknowledgements

This work was realized in the framework of the PYRAMID project (Piping sYstem, Risk management based on wAll thinning MonItoring and preDiction) which is supported by the French National Agency of Research. (ANR-17-CE08-0046) and carried out under the Center of World Intelligence Project for Nuclear S&T and Human Resource Development by the Ministry of Education, Culture, Sports, Science and Technology of Japan. Part of the work was carried out under the Collaborative Research Project of the Institute of Fluid Science, Tohoku University.

References

[1] B. Poulson, Int. J. of Nuclear Energy, 2014, (2014), Article ID 423295, 1-23.
[2] V. Kain, Procedia Engineering, 86, (2014), 576-588.
[3] P. B. Nagy, L. Adler, The J. of the Acoustical Society of America, 82, (1987), 193-197.
[4] J. A. Ogilvy, Ultrasonics, 27, (1989), 69-79.
[5] H. Nakamoto et al. Proc. of 4th Int. Conf. on Maintenance Science and Tech., (2018), 2-3.