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Microwave Measurement and Quantitative Evaluation of Wall Thinning in Metal Pipes

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Abstract

In this paper, wall thinning having values of 3 to 80% pipe thickness were detected significantly. In the experiment, a microwave network analyzer was employed to generate microwave signals propagating in the pipe where the frequency was swept from 47.38 to 47.47 GHz. By building up a resonance model for the microwave signals propagating in the pipe, and by analyzing the resonance results of the microwaves at the receiving port, we derived a nondestructive method that can determine the degree of the wall thinning in the pipe remotely. By comparing the experimental results with those derived by the theoretical analysis, it is shown that the errors of the evaluated results are less than ± 0.5% of the pipe diameter. It indicates that high precision for quantitative evaluation can be achieved by using this nondestructive method.

Key Words: Quantitative evaluation, Metal pipe, Wall thinning, Microwave, Remote detection.

1. Introduction

To the pipes used in industry, such as chemical and power plants, wall thinning is one of the most serious defects[1]. Detection and evaluation of the thickness reduction of pipes are very important issues for the prediction of lifetime of the pipes in order to avoid severe accidents. Recently, many nondestructive testing techniques, such as X-ray[2], Ultrasonic[3, 4], acoustic emission[5], and so on, have been used for the measurement of pipe wall thinning. However, those methods have to move the sensor along the pipe in order to find the area where the thinning occurred. It takes a lot of time and labor, and almost can just be successfully performed by experienced specialists.

In this paper, a novel method which can inspect a metal pipe in a large scale and measure the wall thinning remotely was demonstrated. This method employs a microwave signal to propagate in the pipe, which is considered as a circular waveguide. Therefore the thickness reduction changes the wavelength, thereby changes the resonance frequency of the microwave signal in the pipe.

By building up a resonance model for the microwave signals propagating in the pipe, and by analyzing the resonance results of the microwaves at the receiving port, we derived a nondestructive method that can inspect a large scale of pipes and determine the degree of the wall thinning in the pipe remotely.

2. Experimental Approach

The experimental instrument is composed of a microwave network analyzer (Fig.1 (a)) and a transmitting and receiving coaxial-line sensor (Fig.2). A copper pipe with inner diameter of about 17 mm and length of 900 mm, a group of thickness reduction specimens with reduction of 3%~80% of the pipe wall thickness, *t*, and length of 17 mm (Table.1), and a copper cap to be used to terminate the specimen and form a short-circuit terminal (Fig.1, 2) were used in the experiment.

(a) The microwave instrument for transmitting and receiving microwave signals

(b) Thickness reduction specimen with reductions from 3 to 80%*t* and the terminal cap

Fig.1 Microwave instrument, sensor, cap, and thickness reduction specimens

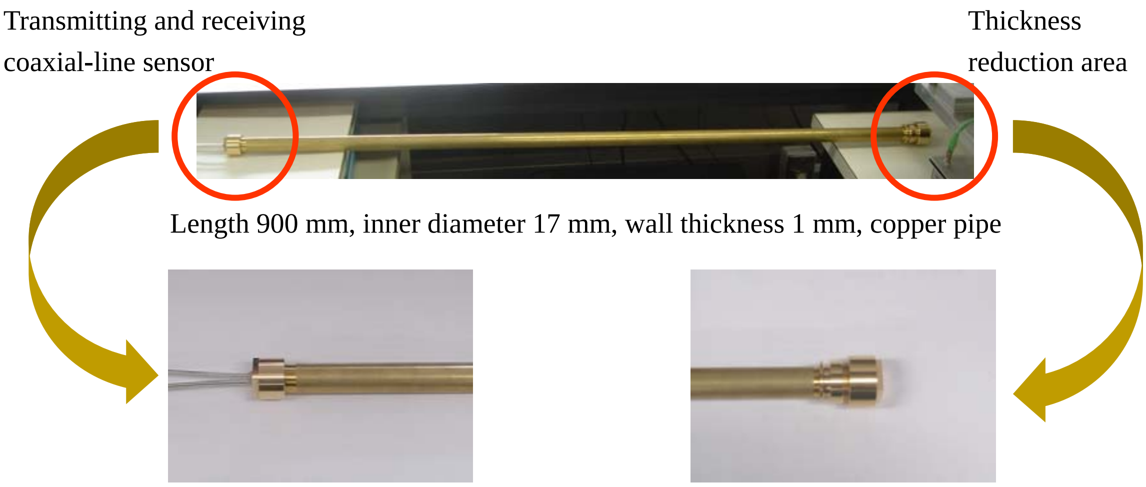

Fig.2 Sensor and the cap connected at the terminal of the experimental specimen

Table 1 Characteristic of pipe thickness reduction specimens

Joint No.	Length (mm)	Inner diameter (mm)	Equivalent pipe wall thickness (mm)	Thickness reduction (%*t*)
1	17	17.06	0.97	3
2	17	17.10	0.95	5
3	17	17.16	0.92	8
4	17	17.20	0.90	10
5	17	17.40	0.80	20
6	17	17.80	0.60	40
7	17	18.20	0.40	60
8	17	18.60	0.20	80

The microwave network analyzer was employed to generate microwave signals propagating in the pipe, which was considered as a circular waveguide. The frequency was swept from 47.38 to 47.47 GHz. The sensor was used to feed the microwave signals into the pipe and draw out them from the pipe.

3. Experimental Results

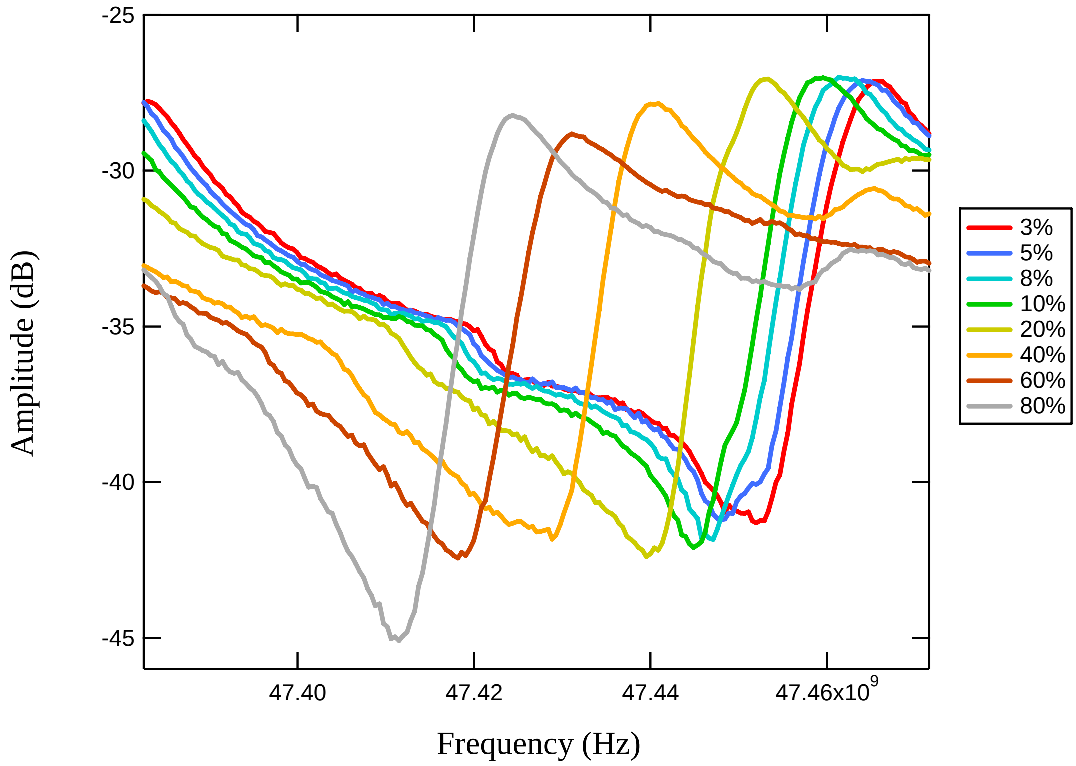

Fig.3 Relationship of amplitude and frequency

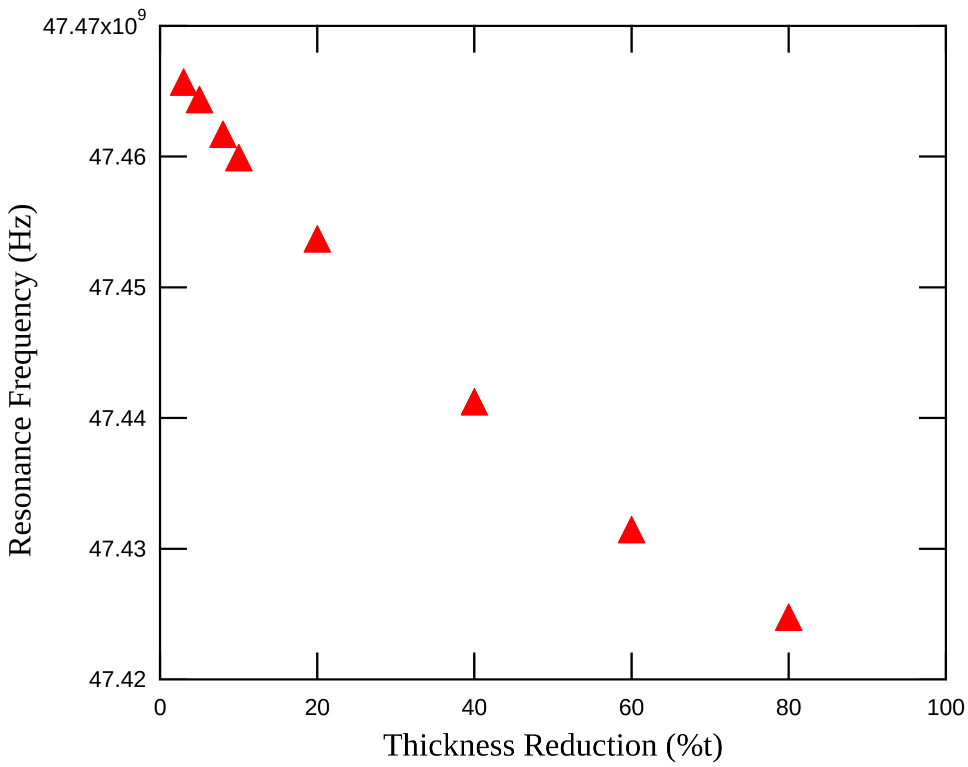

Fig.4 Relationship of resonance frequency and thickness reduction

Fig.3 shows the measured amplitude of the microwave signal versus the sweeping frequency, in the case that the pipe was terminated by the mentioned specimens (see Table 1) and the cap. It can be found that the resonance frequencies are clearly shifting as thickness reduction changes.

Fig.4 shows the resonance frequencies derived from Fig.3 versus the pipe thickness reductions. It can be found clearly that with the increase of the thickness reduction, the resonance frequency decreases gradually. On the guiding wave basis, it is in accordance with the fact that the wavelength of the guiding-wave is correlative with the inner diameter of the pipe.

The experimental results above showed that the resonance frequencies were clearly correlative with degrees of the thickness reductions. Consequently, by analysis of the relationship between the wall thinning degree and the resonance frequency, on the electromagnetic propagation basis, we can promisingly derive a method to inspect a large scale of pipes and measure pipe thickness reduction remotely.

4. Theoretical Analysis

To the pipe thickness reduction problem, the crucial hint for theoretical analysis is the resonance amplitudes, which is composed of the microwaves reflected to the receiving port from the terminal (after propagating along the pipe) and the ones going directly to the receiving port from the transmitting port (along an approximate half-circle-route with diameter of the distance between the two ports).

Our method is the path-tracing method, which is just analyzing the to-and-fro propagation path of the transmitting signal with considering the terminal conditions. Where, the pipe terminated by a cap can be taken as a short-circuit-end condition (with constant-zero voltage at the end, e.g., the reflected wave is with a 180° phase-shift to the transmitting wave at the reflecting end).

By analysis of the propagation paths of the two groups of microwave signals, resonance condition can be derived at the receiving port. In the path-tracing method, we first determine the overwhelming mode for applied frequencies, then to analyze the propagation route, we can derive the thickness reductions by using resonance frequencies.

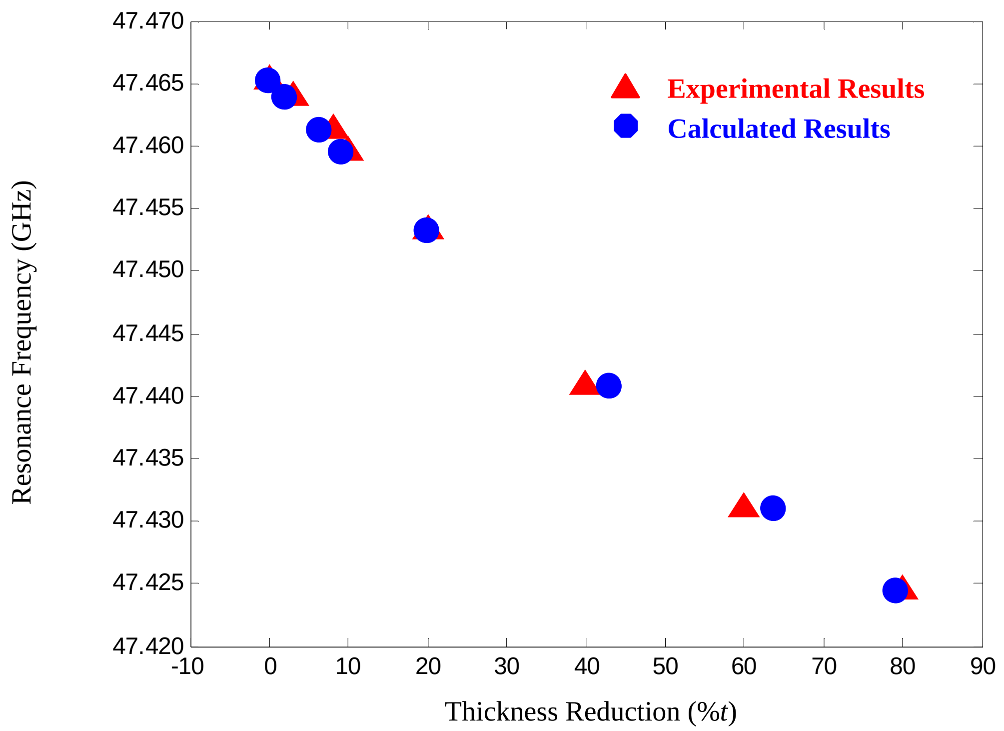

Fig.5 Calculated results vs. experimental results with cap

5. Comparison of the Experimental and Calculated Results

Fig.5 shows a group of comparison of the experimental results and the calculated results, in case of sweeping microwave signals around 47.5 GHz. As shown in Fig.5, the calculated results are in agreement well with the experimental ones.

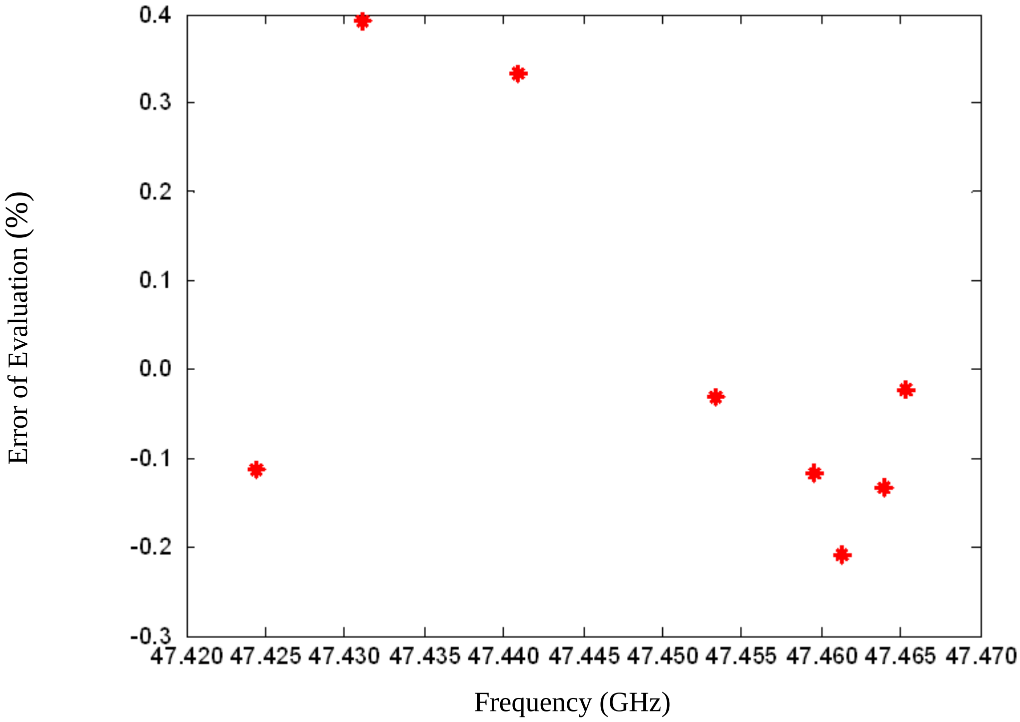

Fig. 6 Error analysis of calculated results vs. experimental results

Fig.6 shows the error analysis results for the difference between the experimental and calculated results as shown in Fig.5. The calculated errors are less than ± 0.5% of the pipe diameter, e.g., less than ± 0.0425 mm of the thickness reduction. They're quite high precisions for general use and quantitative evaluation.

It should be noted that the precisions will partly depend on the wavelengths of the microwaves at applied frequencies generally. In the path-tracing method, we have confirmed the overwhelming mode for such frequencies in the pipe is TE_{02}-mode.

6. Conclusions

As shown above, a group of results for thickness reductions having values of 3 to 80% pipe thickness were detected significantly. By building up a resonance model for the microwave signal propagating in the pipe, and by analyzing the resonance results of the microwaves at the receiving port, we derived a nondestructive method that can determine the degree of the wall thinning in the pipe remotely. By comparing the experimental results with those derived by the theoretical analysis, it is found that the errors of evaluation were less than ± 0.5% of the pipe diameter, which indicates that quite high precisions for quantitative evaluation of wall thinning in the pipe can be achieved by using the path-tracing method.

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