46th Annual Review of Progress in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-6872

STUDY ON QUANTITATIVE DETECTION OF LAMINATION DEFECT IN THICK-WALLED METALLIC PIPE BY USING CIRCUMFERENTIAL GUIDED WAVES

Ziming Li, Zenghua Liu[1], Cunfu He, Bin Wu
College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology
Beijing, China

ABSTRACT

In thick-walled pipe, lamination defect is one type of commonly appeared defects in the manufacturing process. This paper presents a quantitative detection method of lamination defect in thick-walled metallic pipe using circumferential Lamb waves based on wavenumber analysis algorithm. A 3D finite element model is established, and an experimental study is performed with the same setting as the numerical study. Both the numerical result and experimental result are consistent with each other. The reconstructed values show that the lamination is located near the outer surface at nearly about 2.3 mm, which gives a relative error of 15%.

Keywords: thick-walled metallic pipe; lamination defect; circumferential Lamb waves; wavenumber analysis; laser

1. INTRODUCTION

Thick-walled metallic pipes are generally used in power plant pipelines due to its excellent performance under high temperature and high pressure for transporting fluids, such as water, gases, and oil. As one type of defects in the manufacturing process, lamination defects are commonly appeared as sub-surface defects, which are mostly parallel to the pipe surface [1, 2]. The existence of laminations directly reduce the bearing capacity of pipe, and may lead to massive explosions. Thus, it is important to perform a fast and effective nondestructive testing on the detection of lamination defects.

Circumferential guided waves, which is one type of guided waves that propagate along the circumferential direction of pipes, have the advantages of high efficiency, low attenuation, and large-area inspection capability. It has been widely used to detect different types of defects in thick-walled metallic pipes, including notches [3], corrosion [4], etc.. However, the detection of lamination defect is seldom explored. Thus, this paper presents a method of quantitatively detect lamination defect in thick-walled metallic pipe by using circumferential guided waves based on wavenumber analysis algorithm.

2. WAVENUMBER ANALYSIS ALGORITHM

From the dispersion relationships between phase velocity of circumferential Lamb wave mode and frequency-thickness product in metallic pipes, it can be concluded that as the frequency-thickness product increases, the number of wave modes also increases. Thus, in order to obtain a single wave mode for the inspection of lamination defect in thick-walled pipe, a wavenumber filter is needed according to Ref. [5]. The threshold of the filter is decided by the frequency-wavenumber spectrum without defect. The selection of excited wave mode and frequency is referred to Ref. [6], where a wavenumber sensitivity was defined to get the sensitivity of wavenumber with respect to the change of thickness at certain frequency. Fig. 1 plots the wavenumber sensitivity-thickness curves of circumferential Lamb waves at different frequencies (300 kHz, 400 kHz and 500 kHz) in aluminum pipes with same outer radius and different thickness ranging from 0.5 mm to 7 mm by 0.1 mm step. It can be seen that CL_0 mode has greater wavenumber sensitivity when the thickness is small (i,e, lamination appears near the outer surface), while CL_1 mode has greater wavenumber sensitivity when the thickness is large (i,e, lamination appears near the inner surface).

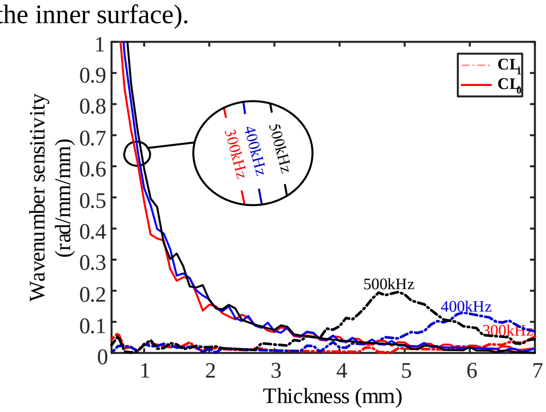


FIGURE 1: WAVENUMBER SENSITIVITY-THICKNESS CURVES OF CIRCUMFERENTIAL LAMB WAVES AT DIFFERENT FREQUENCIES IN ALUMINUM PIPES

[1] Contact author: liuzenghua@bjut.edu.cn

Once the excited wave mode and frequency is chosen, the type of wavenumber filter is confirmed. Then a local wavenumber domain analysis will be performed on the time domain wavefield to get the quantitative result [7]. The algorithm flowchart of quantitatively detect lamination defect in thick-walled pipe is presented in Fig. 2.

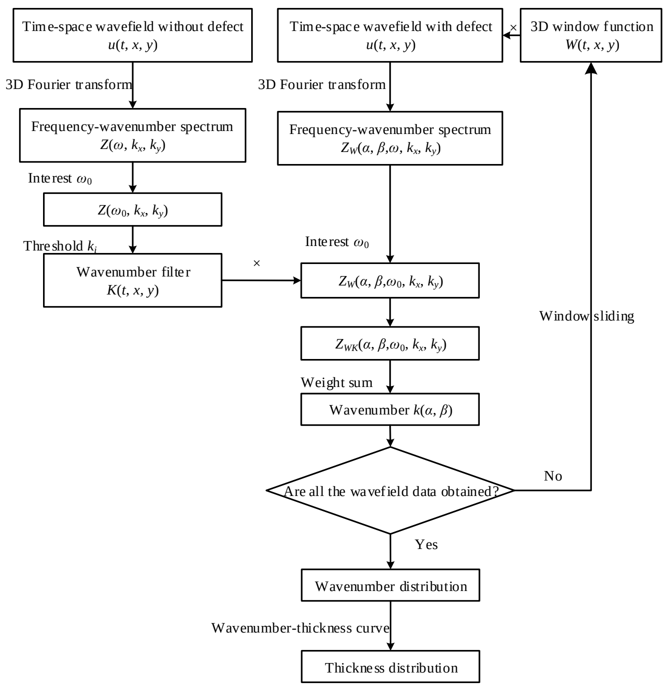


FIGURE 2: ALGORITHM FLOWCHART OF QUANTITATIVELY DETECT LAMINATION DEFECT IN THICK-WALLED PIPE

3. FINITE ELEMENT ANALYSIS

A test specimen with an outer radius of 59 mm and thickness of 6 mm is studied in this research. Owing to the fact that lamination defect is inconvenient to machine in a real metallic pipe, a thick-walled aluminum ring structure is chosen instead of a pipe. The axial length of this ring structure is 30 mm. The lamination defect, which is a through-type defect, is located near the outer surface at 1/3 of thickness, parallel to the surface of the ring, and stretches 30 °along circumferential direction.

A three-dimensional finite element model is established to construct a thick-walled aluminum ring structure by using the parametric programming method, as shown in Fig. 3. A "zero-volume" crack is constructed to simulate the lamination using demerging-node method. Fig. 4 shows the location of excitation and receiving positions in the finite-element model. A five-cycle 0.4 MHz sinusoidal tone-burst signal modulated by a Hanning window is applied at the excitation position. The space intervals of the receiving position are 1 mm along the z direction and 1 ° along the θ direction.

The element type is chosen as C3D8R to mesh the entire part. The element size is set to nearly 0.25 mm×0.25 mm×0.25 mm to ensure the accuracy of the model, and the incremental time step is set into 0.01 μs to maintain the stability of the model.

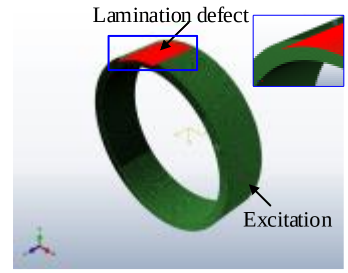


FIGURE 3: 3D FINITE ELEMENT MODEL OF THICK-WALLED ALUMINUM RING STRUCTURE WITH LAMINATION DEFECT NEAR OUTER SURFACE

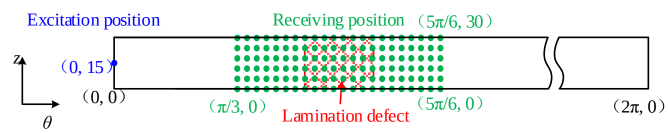
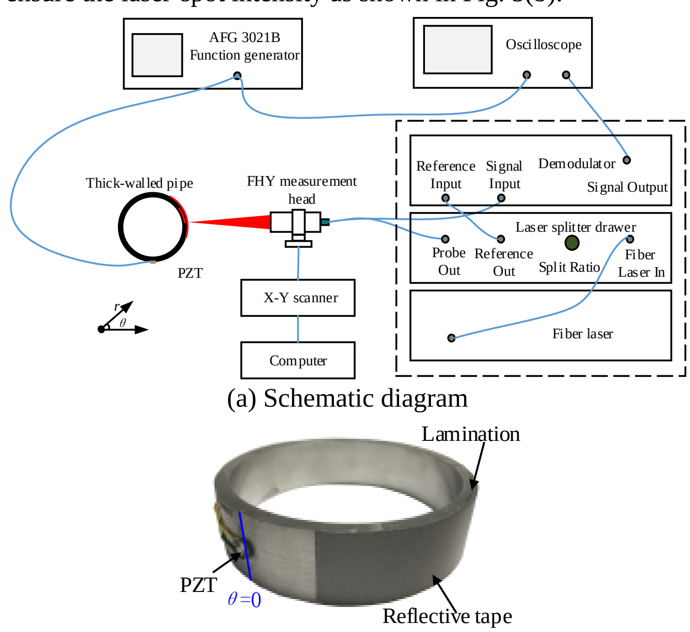


FIGURE 4: LOCATION OF EXCITATION AND RECEIVING POSITIONS IN NUMERICAL MODEL

4. EXPERIMENTAL STUDY

Fig. 5 shows the experimental system. In this system, as shown in Fig. 5(a), the PZT is served as a transducer, which is connected to the function generator that is used to excite the five-cycle 0.4 MHz sinusoidal tone-burst signal modulated by a Hanning window. The laser ultrasonic inspection system (Model LUKS-1550-TWM, IOS Co., USA), including the demodulator, laser-splitter drawer, fiber laser, high-precision FHY measurement head, and other accessories is served as the receiving part. A reflective tape is pasted on the scanning area to ensure the laser-spot intensity as shown in Fig. 5(b).



(a) Schematic diagram

(b) Test specimen

FIGURE 5: EXPERIMENTAL SYSTEM FOR LAMINATION DEFECT DETECTION IN THICK-WALLED ALUMINUM RING

The detailed steps of the entire detection procedure are the same as that presented in Ref. [7].

5. RESULTS AND DISCUSSION

Fig. 6 shows the simulated wavefield snapshots at different times when circumferential Lamb waves interact with the lamination defect near the outer surface in thick-walled aluminum ring. It can be seen that the circumferential Lamb waves propagate gradually from the left side to the right side in the wavefield snapshots. When it meets the entrance of the lamination, an obviously change can be observed by the naked eye. As these waves go on propagating, they encounter the exit of the lamination, and generate another obvious change. Then a complicated reverberation can be seen in the lamination area.

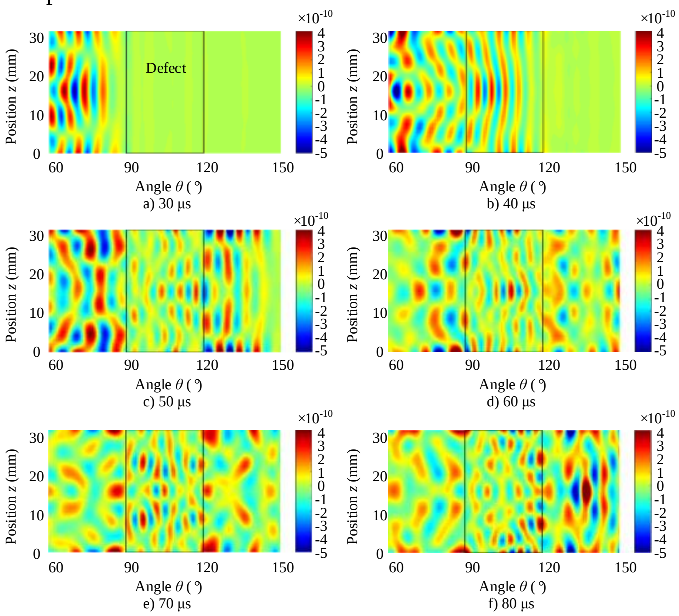


FIGURE 6: SIMULATED WAVEFIELD SNAPSHOTS AT DIFFERENT TIMES

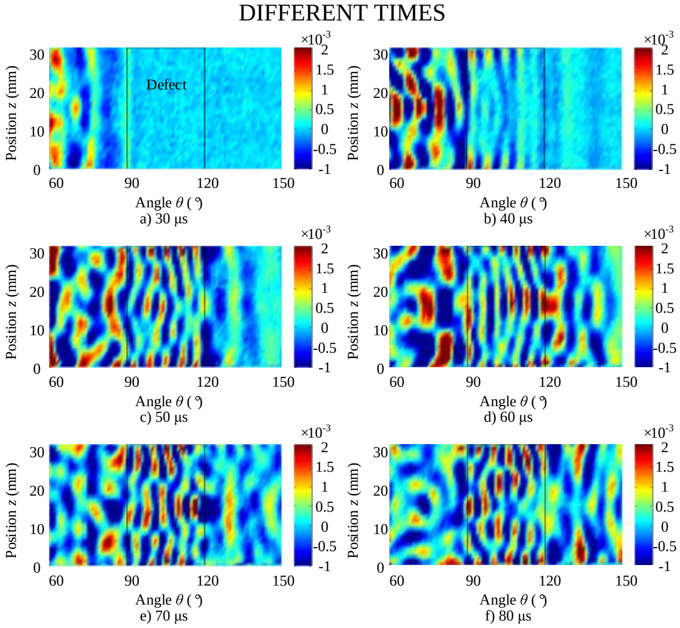
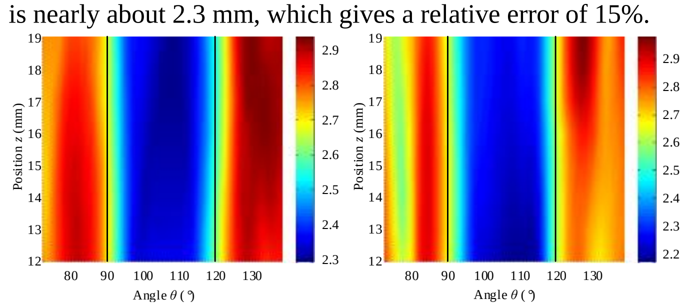


FIGURE 7: EXPERIMENTAL WAVEFIELD SNAPSHOTS AT DIFFERENT TIMES

Fig. 7 shows the experimental wavefield snapshots at different times when circumferential Lamb waves interact with the lamination defect near the outer surface in thick-walled aluminum ring. It presents the same propagation phenomena with the numerical result.

Fig. 8 shows the reconstruction results of the space-thickness distribution by using the wavenumber analysis algorithm in both numerical study and experimental study. They are well consistent with each other, and the blue areas indicate lamination defect. The reconstructed location of lamination area is nearly about 2.3 mm, which gives a relative error of 15%.



a) Numerical study b) Experimental study

FIGURE 8: RECONSTRUCTION RESULT OF THE SPACE-THICKNESS DISTRIBUTION

4. CONCLUSION

In this paper, a method of quantitatively detect lamination defect in thick-walled metallic pipe by using circumferential Lamb waves based on wavenumber analysis algorithm is performed. Both numerical study and experimental study are presented to obtain good consistent results. The results show that the reconstructed location of lamination area is nearly about 2.3 mm, which gives a relative error of 15%.

ACKNOWLEDGEMENTS

The study was supported by the National Natural Science Foundation of China (Grant Nos. 51475012, 51235001, and 11772014) and the Scientific Research Project of Beijing Educational Committee (Grant No. KM201010005003).

REFERENCES

[1] C. Hayashi, T. Yamakawa. Influences of feed and cross angle on inside bore and lamination defects in rotary piercing for materials with poor hot workability. *ISIJ International*. 1997,37(2):153–160.

[2] P. G. Fazzini, A. P. Cisilino, J. L. Otegui. Experimental validation of the influence of lamination defects in electrical resistance seam welded pipelines. *International Journal of Pressure Vessels and Piping*. 2005,82:896-904.

[3] Z. H. Liu, Q. L. Xu, Y. Gong, C. F. He, B. Wu. A new multichannel time reversal focusing method for circumferential Lamb waves and its applications for defect detection in thick-walled pipe with large-diameter. *Ultrasonics*, 2014,54(7):1967-1976.

[4] M. Clough, M. Fleming, S. Dixon. Circumferential guided wave EMAT system for pipeline screening using shear horizontal ultrasound. *NDT & E International*, 2017,86:20-27.

[5] L. Y. Yu, Z. H. Tian, C. A. Leckey. Crack imaging and quantification in aluminum plates with guided wave wavenumber analysis methods. *Ultrasonics*, 2015,62:203-212.

[6] T. C. Truong, J. R. Lee. Thickness reconstruction of nuclear power plant pipes with flow-accelerated corrosion damage using laser ultrasonic wavenumber imaging. *Structural Health Monitoring*, 2018,17(2):255-265.

[7] Z. M. Li, C. F. He, Z. H. Liu, B. Wu. Quantitative detection of lamination defect in thin-walled metallic pipe by using circumferential Lamb waves based on wavenumber analysis method. *NDT & E International*, 2019,102:56-67.