NON-CONTACT INSPECTION TECHNIQUE OF TUBE USING LASER ULTRASONICS

H. M. Kim[+], K. I. Jung[+], K. Y. Jhang[+], H. K. Ann[#], N. G. Kwag[#] and C. M. Lee[#]
+School of Mechanical Engineering, Hanyang University, Seoul, Korea
#Sae-An Engineering Corporation, Seoul, Korea
mookstory@hanmail.net

Abstract

Ultrasonic guided wave has been widely used for the tube inspection. The conventional method is to use piezoelectric transducers that should be contacted to the target surface. However, in order to inspect tubes used in high temperature in-service, non-contact inspections are necessary. In this paper, we have proposed a non-contact inspection method generating the ultrasonic guided wave by laser and receiving by air-couple transducer. This method can generate and receive the guided wave of a specific mode, which makes the interpretation of received signal clearer and resultantly improves the accuracy of inspection. Also the detected signal was analyzed by using the wavelet transform and is useful for the mode identification. The proposed method was applied to the tube specimen with artificial defects and its inspection performance was verified. Finally we have developed a practical automatic inspection system, in which the inspection result is shown as a 2-D image.

Introduction

Industrial facilities such as nuclear power plant or chemical plant are mostly composed of pipe and tube structures that require high level of integrity, since their failure may cause severe economic and social damages. Therefore, it is necessary to develop methods to assess reliability of tube structures and components in the manufacturing process and in operation.

There have been many active theoretical and experimental researches on the tube inspection using the guided ultrasonic waves in 1990s [1]. The application to the steam generator had shown its possibility [2]. However, the conventional method using piezoelectric transducer requires contacting transducer to the specimen, which also needs couplant and suitable wedge. This makes automation of inspection difficult, and also it has limit in the application to high temperature environment. Therefore, we need a non-contact method where the guided ultrasonic wave can be generated and received without any contact. The laser-ultrasonic technique is considered as a useful method [3].

The objective of this research is to develop an automatic non-contact tube inspection technique that generates the ultrasonic guided wave by laser and receives by air-couple transducer, which includes signal processing to analyze the mode of guided wave and image processing to show the inspection result as a rotationally scanned image.

Experimental Details

Figure 1 is a block diagram of the system and Photo. 1 is its photograph. The slit mask is used to achieve the linearly arrayed light illumination that acts as the line array source of ultrasonic guided wave on the surface of target [4]. This linear array source generates the axial longitudinal mode dominantly that propagates mainly along the axial direction of tube. Also the spacing of array coincides with the wavelength of guided wave to be generated, so that we can select the specific mode that we want to generate by simply changing the slit spacing. This is great advantage to interpret the wave signal, since the modes of guided wave that can propagate in tube is very complicated. Figure 2 shows the mode to be generated in our case from the relationship between the wavelength and phase velocity, and 3 kinds of mode on the group velocity curve in case of 4mm wavelength [5].

In our system, the air-coupled transducer is used as

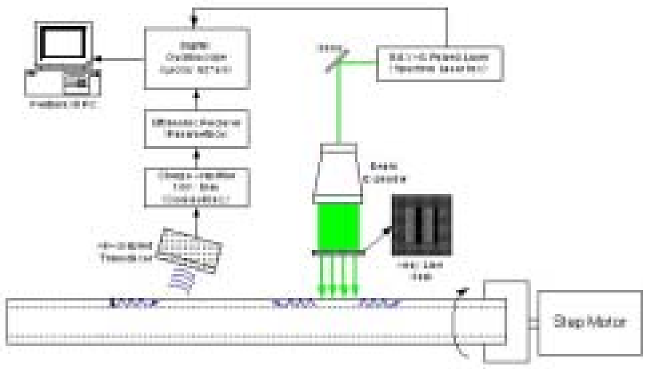


Figure 1 Block diagram of System

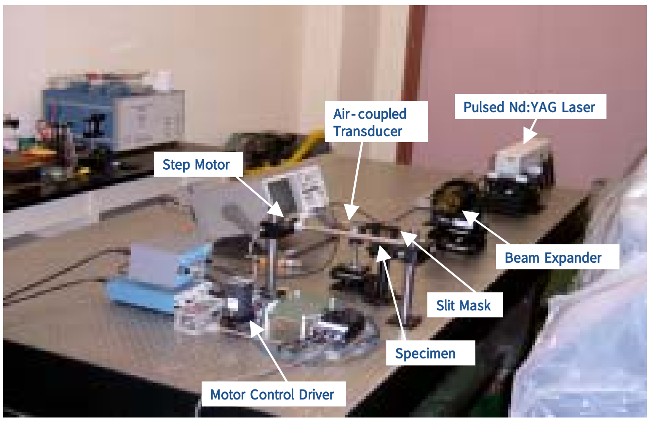


Photo. 1 Scene of the system

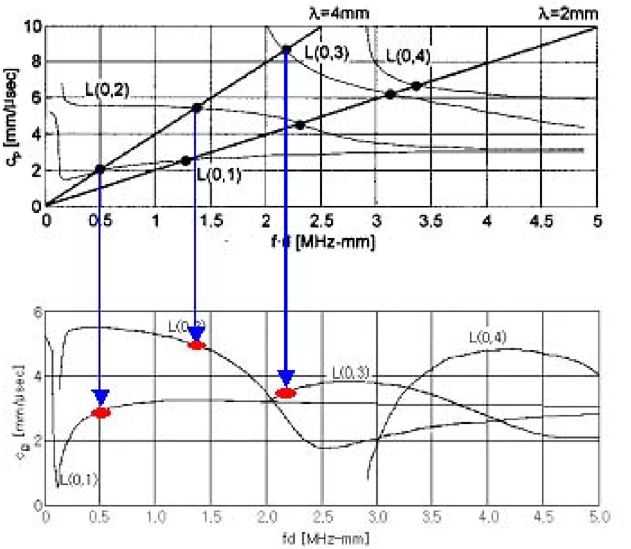
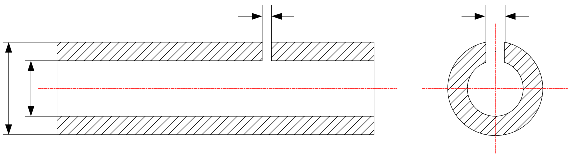
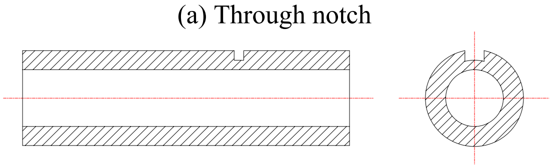


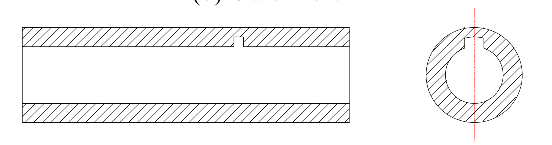
Figure 2 Relationship wavelength and sound velocities



(a) Through notch



(b) Outer notch



(c) Inner notch

Figure 3 The shape of the artificial EDM notch in stainless tube

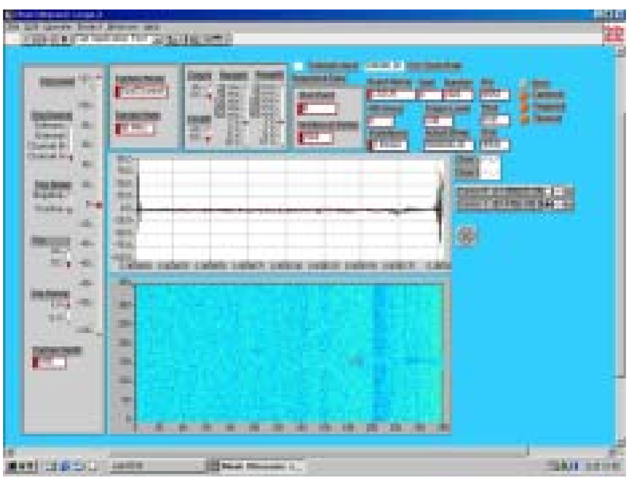


Figure 4 Inspection software of 2D-image

the receiver that detects the leak component of Lamb wave [6]. It can detect a specific mode of guided wave by controlling the oblique angle of transducer. This angle is calculated by phase velocity estimated from theoretical dispersion curve and sound velocity in the air.

Received signal was amplified and filtered for cutoff the mechanical noise. For automated inspection, tube was rotated with step motor.

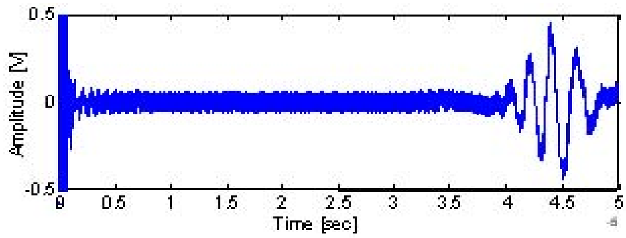
Artificially fabricated notch is shown on Figure 3. Width of notch is 0.1mm and circumferential length was between 2~8mm. Also, to assess circumferential length of the notch, we have displayed the received signal into scanned images in real time, so it is easier to decide the location and size of defects. Figure 4 shows the sample screen of the developed software of image processing.

Results and Discussion

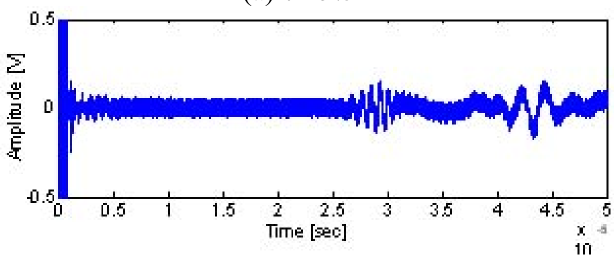
Figure 5 shows waveforms received when a mask with slit interval (λ) of 4mm has been used. As shown in Figure 2, we have estimated that modes L(0,1), L(0,2) and L(0,3) would be created. From each phase velocity, we have calculated oblique angle of transducer to be received. (a) is a waveform of L(0,1) mode and (b) of L(0,2). L(0,3) mode was not received because it exceeds the reception frequency range (1~2.25MHz) of air-coupled transducer.

Figure 6 shows the received waveforms, which had been wavelet transformed, in time-frequency contour plot. As shown in the image, the modes theoretically estimated and the modes received through experiment coincide well each other.

Figure 7 shows the waveform obtained from the stainless steel specimen with artificial notch defects. As shown in the image, circled No.1 is the reflected wave from the notch and No. 2 is from the end of the tube.

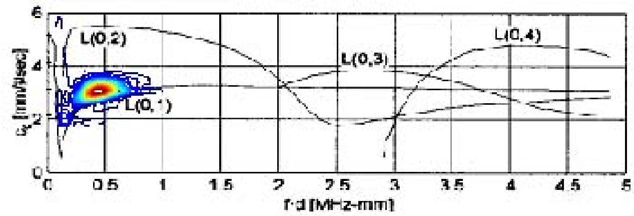


(a) θ= 9.5°

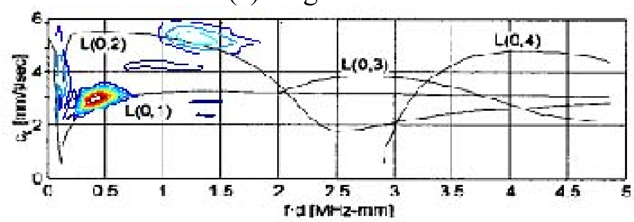


(b) θ = 3.5°

Figure 5 Waveform from predicted angle of transducer with slit mask (λ=4mm)

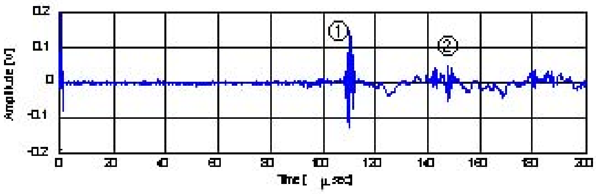


(a) Angle = 9.5°

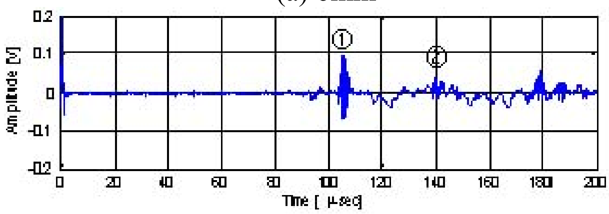


(b) Angle = 3.5°

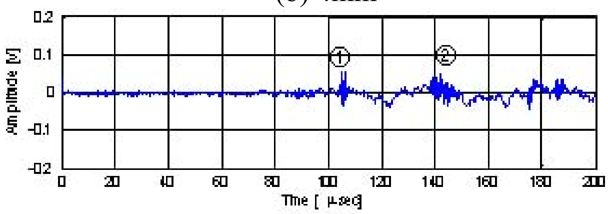
Figure 6 Group velocity dispersion curve and contour plot from wavelet transform



(a) 6mm



(b) 4mm

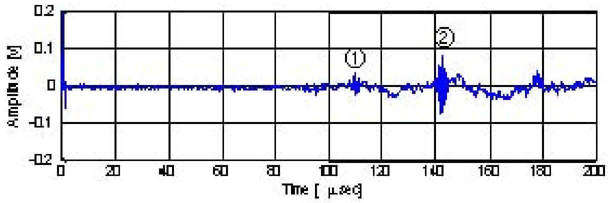


(c) 2mm

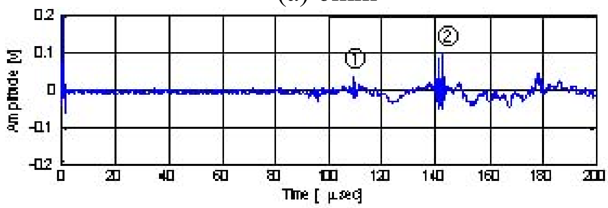
Figure 7 Signals of detection for through wall notch in tube

In case of through wall notch, it was easy to find out 2mm notch. Figure 8 is inspection signals for outer notch and Figure 9 is the inspection signals for inner notch. Inner notch had rather small amplitude compared to outer notch. As of results above, it was proven that it is possible to inspect defects existing in the inside and outside of the tube. However, there may be limitation in deciding geometrical location of defects from received wave. Thus further researches on methods that can distinguish inner and outer defects from the received signal are demanded.

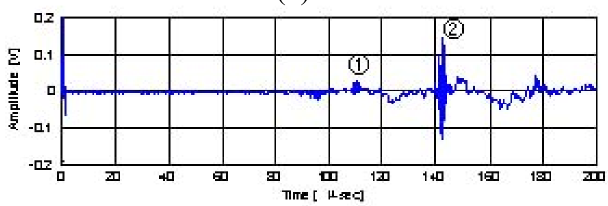
As for a method of measuring circumferential length of the notch, we have developed the image display of the scanning result in real time. Figure 10 is the scanning image for 6mm long through wall notch.



(a) 6mm

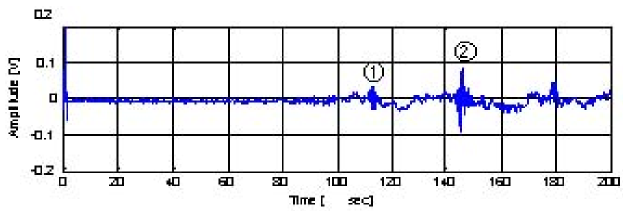


(b) 4mm

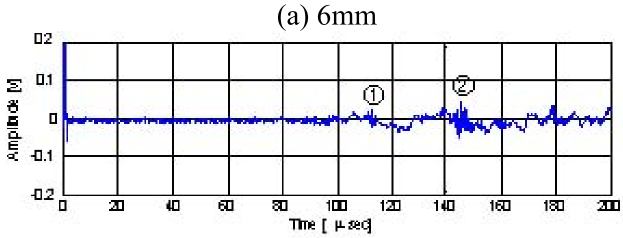


(c) 2mm

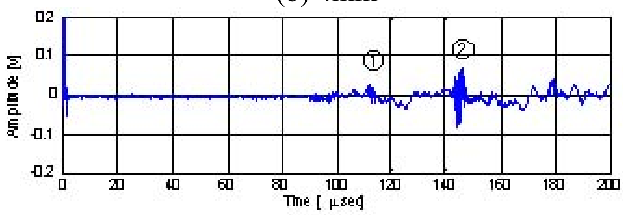
Figure 8 Signals of detection for inner notch in tube



(a) 6mm



(b) 4mm



(c) 2mm

Figure 9 Signals of detection for outer notch in tube

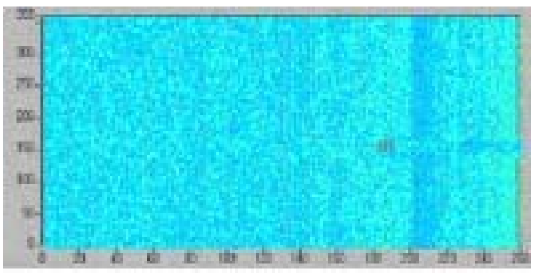


Figure 10 The two dimensional image of through wall 6mm notch

In the image, x-axis is the tube length and y-axis is the rotation angle. We can see that the defect is located over 32 degrees of rotation angle. Then, since the diameter of tube is 20mm, unit degree of the rotation angle is corresponding to 0.175mm. Therefore, the circumferential length of defect becomes to be 5.6mm. It coincides with the actual notch length accurately.

Conclusions

It was possible to generate the guided ultrasonic wave by using the laser illumination on the tube and to control the mode to be generated by using the line array slit. In this study, the longitudinal mode was dominantly generated, which propagated along the axial direction of cylindrical tube. Therefore, only axial longitudinal modes could be generated. Such result has been verified through time-frequency analysis that used wavelet transformation.

Guided ultrasonic was received effectively by the air-coupled transducer and a method of receiving a specific mode selectively has been developed.

It was possible to inspect notches existing in the tube using the proposed inspection system, where the location and size of defects could be displayed in the 2 dimensional scanning image in real time.

Acknowledgements

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