The Development of Laser Ultrasonic Visualization Equipment and its Application in Nondestructive Inspection

Bo WANG [1], Junji TAKATSUBO [2], Nobuyuki TOYAMA [2], Mingying ZHAO [3]

[1] Tsukuba Technology Co., Ltd; Belle flora 101, Sengen 1-9-1, Tsukuba, 305-0047, JAPAN.
Phone: +81-29-8527777, Fax: +81-29-8865528; e-mail: wangbo@tsukubatech.co.jp
2. Research Institute of Instrumentation Frontier, AIST; Tsukuba, JAPAN. e-mail: takatsubo.j@aist.go.jp
3. Xidian University; Xi'an, CHINA; e-mail: zmy9912@163.com

Abstract

We have developed a laser ultrasonic visualization(LUV) equipment. It can be used to study the ultrasound propagation in an arbitrary-shaped object, and also be used to the nondestructive inspection of materials and structures. The LUV equipment consists of the hardware and the software. The hardware consists of a pulsed laser, a scanning mirror (galvanometer scanner), an ultrasound sensor, a low noise amplifier, a high speed AD converter and a computer. The software, developed using LabVIEW and C++ language, includes the system control, data acquisition, signal processing, image processing, visualization and defect diagnosis. The LUV equipment can scan the specimen at 1 kHz and the space resolution can reach to 0.1mm. Using the LUV equipment, the ultrasound propagation process can be observed and defects, such as cracks in a metal object, corrosions in a steel tube, delamination in the CFRP material, debonding in the composite structure, can be found easily. This paper will mainly introduce the configuration of the LUV equipment, and some applications in nondestructive inspection. The principle and technique details will be introduced in another paper of this conference.

Keywords: Laser, Ultrasound, Visualization, Nondestructive inspection.

1. Introduction

In the field of nondestructive test, the ultrasonic inspection is a popular, low-cost and convenient technique. However, the propagation characteristics of ultrasonic waves vary depending on the type, bonding condition, mounting position of the sensor, and the material of samples. These characteristics are also influenced by complex geometry parts; in particular, reflected waves, refracted waves, and mode transformation waves mutually interfere. So it is difficult for even a skilled inspector to identify the defect accurately from received waveforms within a short time. If inspections could be conducted while visually observing the propagation of ultrasonic waves in a simple manner, it would be easier to identify the defect. Furthermore, such visualization would also contribute significantly to basic fields such as clarifying how waves propagate and exploring new ultrasonic-wave phenomena. The usefulness of visualizing ultrasonic waves in this way has been confirmed, and now attempts are being made to visualize ultrasonic-wave propagation by the photo elasticity method [1, 2], the receiving probe scanning method [3, 4], and computer simulation [5-7] to support ultrasonic non-destructive flaw detection. However, these methods have shortcomings, such as being applicable to only transparent objects, inability to accommodate arbitrary three-dimensional objects, requiring sophisticated device adjustment resulting in poor operability, and requiring much time for measurement and analyses. It is therefore practically impossible to apply them to actual structures.

To overcome these problems, we developed a novel LUV technique [8] that generates thermal-excitation ultrasonic waves on a specimen through pulsed laser scanning and detects the propagating signals via a reception transducer attached at a fixed point. Images of ultrasonic waves propagated from a fixed point are created using the reciprocity principle of sound propagation. Based this technique, we have developed the LUV equipment. Using the equipment, we can obtain visualized dynamic images of ultrasonic waves propagation. Moreover, we can easily find the damages, such as cracks in a metal object, corrosions in a steel tube, delaminations in a CFRP material, debonding in the composite structure.

2. System Configuration

The LUV equipment consists of the hardware and the software. The hardware, as shown in Fig.1 schematically, consists of a pulsed laser, a scanning mirror (galvanometer scanner), an ultrasound sensor, a low noise amplifier, a high speed AD converter and a computer. The software, developed using LabVIEW and C++ language, includes the system sync control, data acquisition, signal processing, image processing, visualization and damage diagnosis. In this system, the pulsed laser can be directed to any point virtually ignoring the incidence angle and focal length of the laser and the laser beam is scanned by a dual axes rotation mirror at high speed. The propagated ultrasound signals are received by the ultrasound sensor attached to the specimen. The computer records the received ultrasound signals via the low noise amplifier and the high speed A/D converter. The fig.2 shows the ultrasonic propagation visualized image of a stainless steel elbow with an inner corrosion for each 10μs of propagation time. The amplitudes of the array of these waveforms measured simultaneously correspond to the displacement of the ultrasonic wave at each laser radiation point if the reciprocity of ultrasonic propagation is utilized. Therefore, when an image of that intensity modulated by the amplitude is created and sequential images are acquired in the order measurement time, an image of ultrasonic waves that appear to be generated at the positions of receiving sensor can be obtained. This is not an image of actually propagating ultrasonic waves, but it is based on actually measured data, so it is the image of such ultrasonic waves that actually exist. Laser beams are scanned and waveforms incorporated at 1 kHz intervals, so it takes about 10 seconds to incorporate an array of waveforms of 100 points by 100 points.

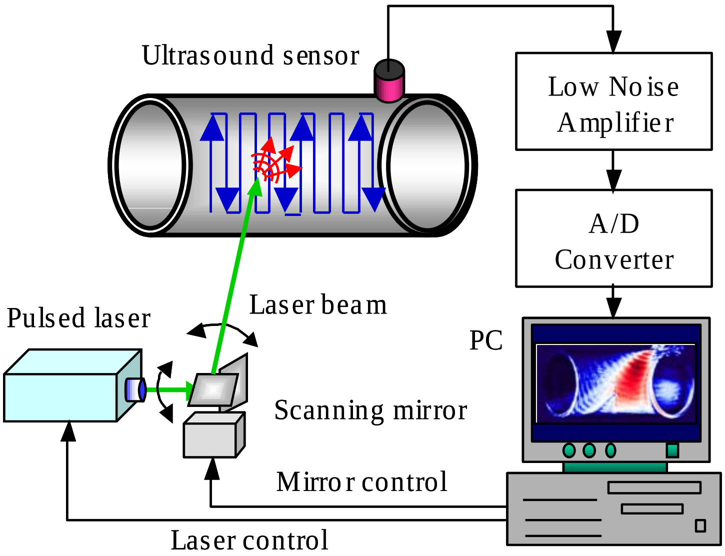

Fig. 1 LUV System Configuration

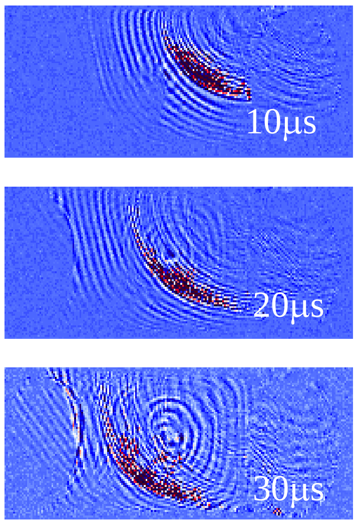

Fig.2 Ultrasonic propagation image of a stainless steel elbow with an inner corrosion

3. Some Applications in Nondestructive Inspection

Using this LUV equipment, we have performed various experiments of ultrasound visualization and nondestructive inspection to the several kinds of materials and structures. These results verified that the LUV technique and equipment are very useful and can be applied to the ultrasound visualization study and nondestructive inspection. Here, several visualization examples will be exhibited.

Fig.3 shows the ultrasonic propagation images of an aluminum tube with a small hole. From these images, we can clearly observer the ultrasonic propagation state around a small hole in the aluminum tube, and can easily find the defect.

Fig.4 presents the ultrasonic visualization images propagating on two T-shaped stainless steel pipes. The left one is a defect pipe with an inner artificial corrosion, the right one is healthy pipe. Although the laser beam only scans the surface of pipes, the defect of inner corrosion can be easily detected.

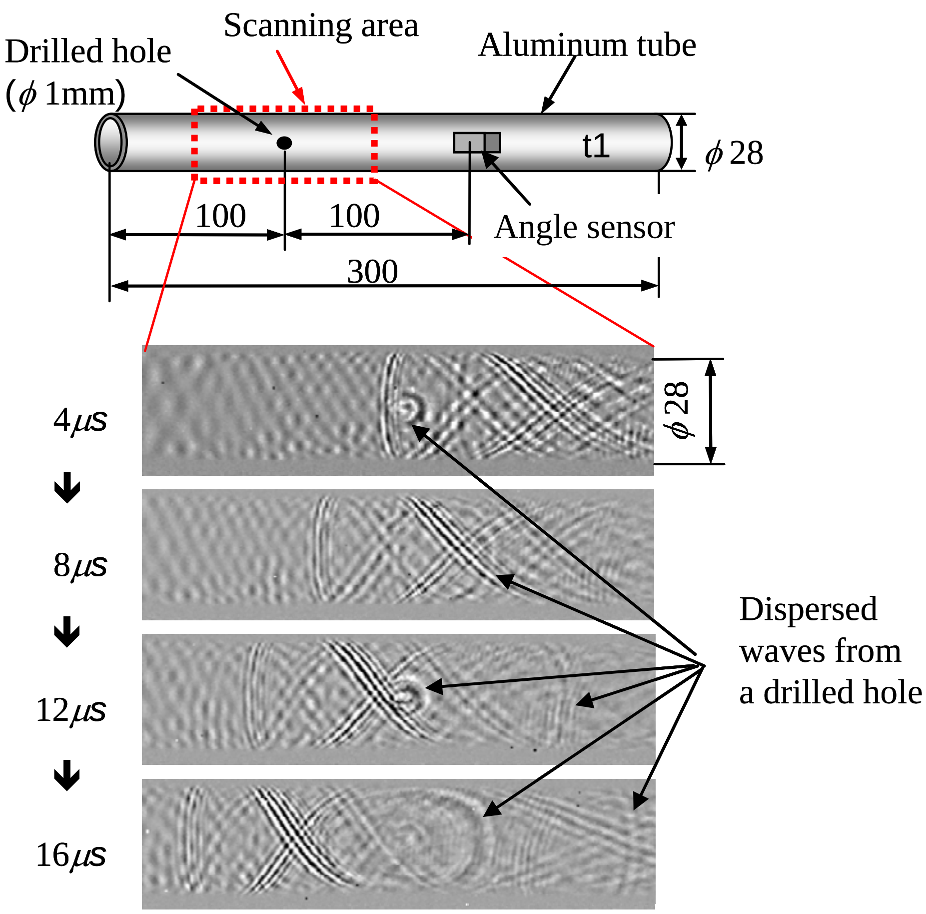

Fig.3 Ultrasonic propagation images of an aluminum tube with a small hole

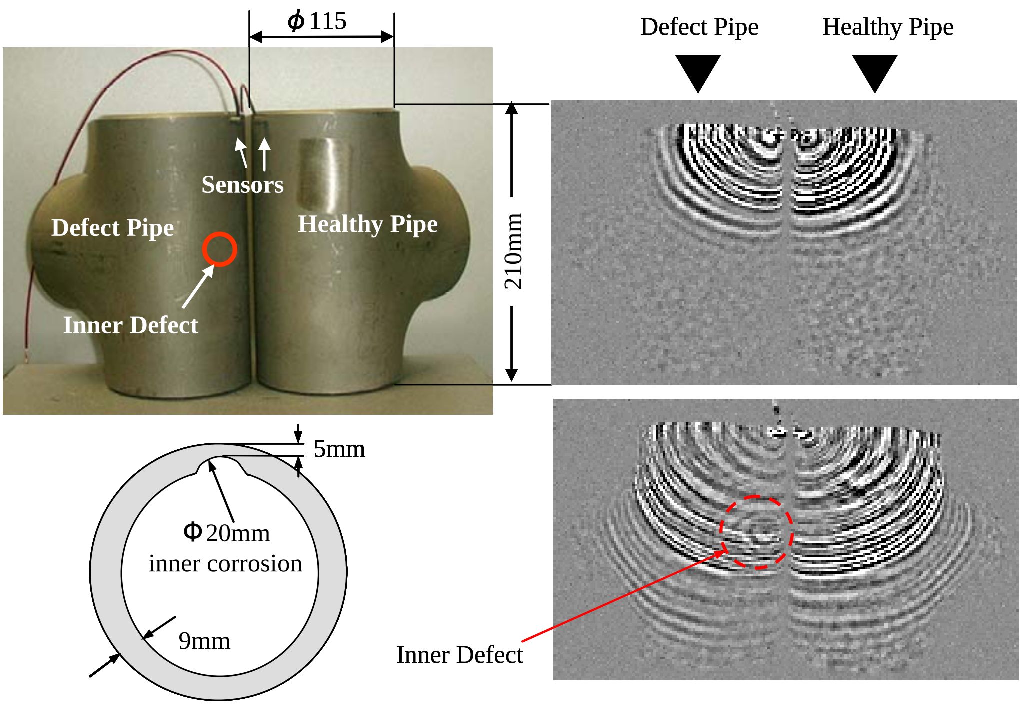

Fig.4 Ultrasonic dynamic Visualization images propagating on two T-shaped stainless steel pipes, the left one with an inner corrosion

Fig.5 exhibits the visualization images of ultrasonic waves propagating on a CFRP $[0/90]_{4S}$ specimen having a delamination with a hammer striking. The CFRP specimen is a cross-ply laminated plate with dimensions of 290mm × 190mm × 2.3mm, which was partially delaminated by striking it with a hammer. The ultrasonic propagation was visualized by a mounted PZT sensor (300 kHz central frequency) on the back side and laser scanning on the front side (over a range of 100mm × 100mm around the sensor position). The disturbance in waveform after the ultrasonic wave has passed the delaminated section is visualized. Furthermore, the anisotropy with sonic velocity of the S0 wave and the isotropy with sonic velocity of the A0 wave are also clearly observed.

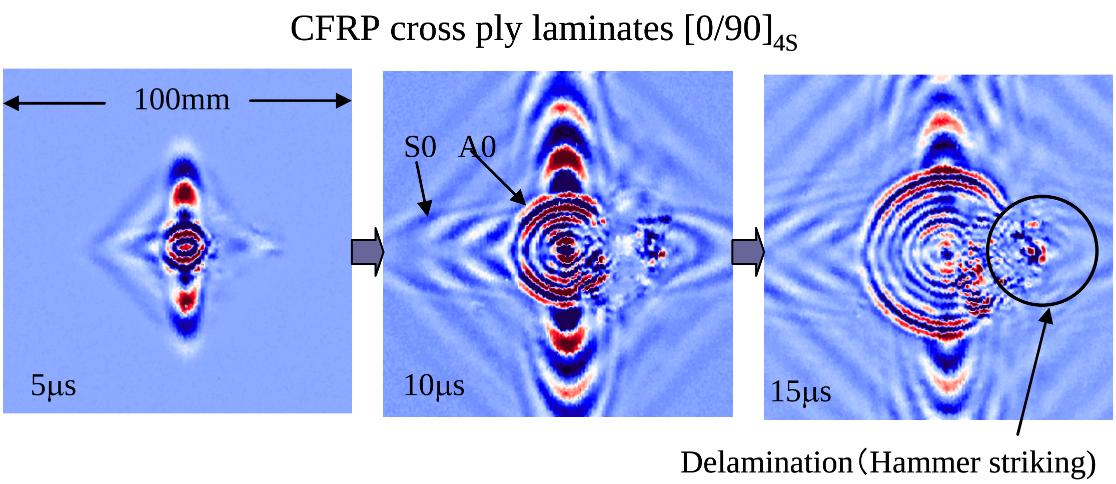

Fig. 5 Visualization of ultrasonic waves propagating on a CFRP$[0/90]_{4S}$ specimen having a delamination with a hammer striking.

Fig. 6 depicts the visualization images of the ultrasonic propagation around a debonded area of the CFRP hat stringer sample of an airplane. Both the stiffener and skin of the sample were made of 3mm-thick CFRP quasi-isotropic laminated plate. The bonded corner section between them was debonded using a scraper (indicated by the red circle in the figure), and the difference in ultrasonic propagation between the intact section and debonded section was visualized. The high-sensitivity PZT sensors (nominal frequency 300 kHz) were used, and with sensors mounted on the surface of the hat and the skin, as depicted in the photo (left side of the fig.6), the ultrasonic waves generated (actually received) by the sensor on the skin, which propagate on the hat stiffener, and the ultrasonic waves generated on the surface of the hat, which propagate on the backside of the skin, were visualized. The image of ultrasonic propagation on the backside (bottom of Fig. 6) is inverted from the image of ultrasonic propagation on the surface shown at the top due to the measurement method. These ultrasonic propagation images should be vertically symmetric if there is no debonding. However, the visualized images are obviously asymmetric, so any debonding in the hat slinger sample can be detected just by detecting this asymmetry. The amplitudes of ultrasonic waves passing through the debonded section are considerably lower than those in the intact section because the air layer produced by debonding makes it difficult for ultrasound propagation.

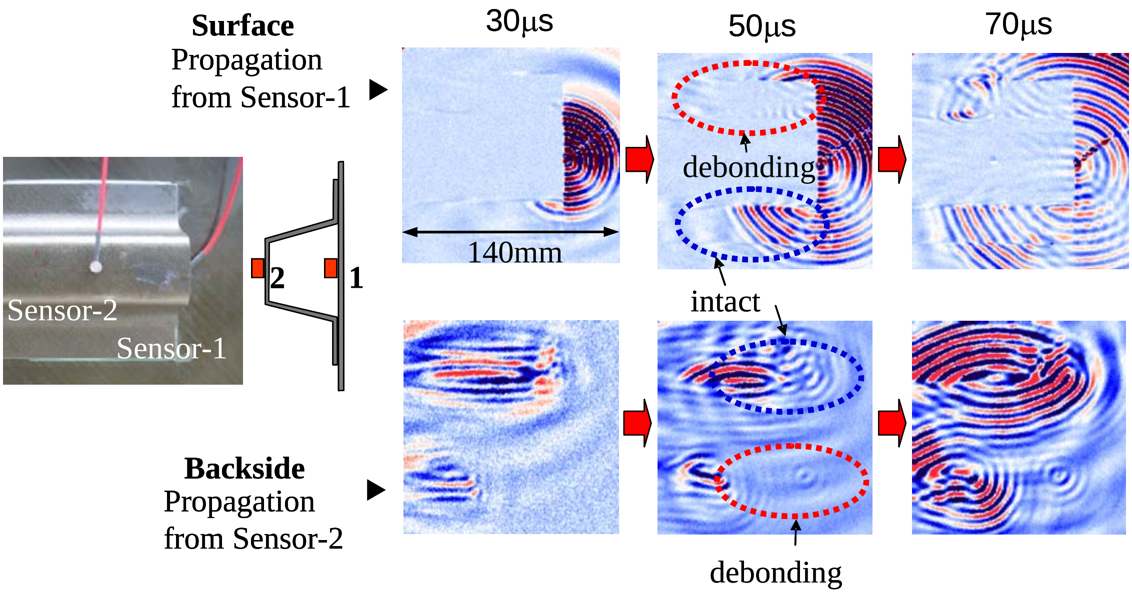

Fig.6 Visualization images of the ultrasonic propagation around a debonded area of the CFRP hat stringer sample

4. CONCLUSIONS

We have developed a laser ultrasonic visualization (LUV) equipment that generates thermal-excitation ultrasonic signals on a specimen through pulsed laser scanning, and detects the propagation signals via an ultrasound sensor attached at a fixed point. Using this LUV equipment, the ultrasound propagation process can be observed and defects, such as cracks in a metal object, corrosions in a steel tube, delamination in the CFRP material, debonding in the composite structure, can be found easily. The many experiment results demonstrate the LUV equipment is a novel ultrasound inspection instrument. It can be used to study the ultrasound propagation in an arbitrary-shaped object, and also be used to the nondestructive inspection of materials and structures in a short time. The LUV equipment has the following features:

- It can be used to visualize the 3-D complex-shaped objects.
- It provides excellent working efficiency.
- It enables us to remotely measure images in a short time.

  Max distance (between the mirror and the object): 10m

  Max scanning speed: 2 kHz

◆ It enables us easily and quickly to perform the nondestructive inspection.

This technology was developed by the Research Institute of Instrumentation Frontier, AIST; JAPAN. It has been transferred to the AIST venture company—TSUKUBA TECHNOLOGY CO., LTD.. The details about the LUV products can be found from the Company's website (http://www.tsukubatech.co.jp).

References:

[1] H. Tretout, "Review of Advanced Ultrasonic Techniques for Aerospace Structures", NDT.net - September 1998, Vol.3 No.9.

[2] K. L. Dilhan, D.L. David, C. Emmony, "Schlieren imaging of laser-generated ultrasound", Appl. Phys. Lett., Vol. 79, No. 20, 2001, pp3356-3357.

[3] Y. H. Nam, S.S. Lee, "A quantitative evaluation of elastic wave in solid by stroboscopic photoelasticity", J. Sound and Vibration, Vol. 259, No. 5, 2003, pp1199-1207.

[4] M. Tsuyoshi, "Visualization of propagation of ultrasounds by photo-elastic imaging process" (in Japanese), Trans. of the Visualization Soc. of Jpn., Vol.118, No.70, 1988, pp181-186.

[5] T. Hayashi and K. Kawashima, "Analysis of flexursl mode focusing by a semianalytical finite element method", J. Acoust. Soc. Am., Vol.113, No.3, 2003, pp1241-1248.

[6] H. Yamawaki and T. Saito, "Numerical calculation of ultrasonic propagation with anisotropy", NDT & E Int., Vol.33, Issue7, 2000, pp489-497.

[7] B. Wang, J. Takatsubo, et al., "An Improved Ray Tracing Algorithm for Ultrasonic CT in Nondestructive Inspections", Proceedings of the 8th international Conference on Signal Processing, Vol.1, pp5-8. Nov. 2006 in Guilin, CHINA.

[8] J. Takatsubo, B. Wang, H. Tsuda and N. Toyama, "Generation laser scanning method for the visualization of ultrasounds propagating on a 3-D object with an arbitrary shape (in Japanese)", Trans. of the Jpn. Soc. of Mech. Engineers, Series A, Vol.72, No.718, 2006, pp945-950.