Optik 127 (2016) 415–419

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Detection of surface defects for longitudinal acoustic waves by a laser ultrasonic imaging technique

Wei Zeng[a,b,*], Haitao Wang[b], Guiyun Tian[b], Wen Wang[a]

[a] School of Physics and Electronic Electrical Engineering, Huaiyin Normal University, China
[b] College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

ARTICLE INFO

Article history:
Received 12 November 2014
Accepted 25 September 2015

Keywords:
Pulsed laser
Surface damage
The velocity
Longitudinal acoustic waves
Laser ultrasonic imaging technique

ABSTRACT

The main objective of this paper was to use the p-waves to quantitatively evaluate the surface cracks by a laser ultrasonic imaging technique. The p-waves were generated by a pulsed laser illuminated on the specimen with a surface damage and received by a piezo transducer. According the relationship between the propagation distances with the p-waves velocity, we analyzed the time (1.5 μs) of the maximum forward amplitude of the once P-waves arrived at the receiver when the pulse laser illuminated at different excitation points, and analyzed the vibration of the p-waves at different distance from the surface damage at 1.5 μs. At last, C-scan image and estimated size and location as determined by p-waves amplitude at 1.5 μs were used to detect the sizes of the damage. The experimental results showed that using longitudinal acoustic waves by a laser ultrasonic imaging technique is an effective way for the investigation of surface damage.

1. Introduction

In order to detect different kinds of manufacturing damages and in-service defects, a large number of non-destructive testing (NDT) methods are proposed to avoid catastrophic failure or costly repairs. Surface cracks are the common type of defects in the production process, and the conventional methods for detection of surface cracks are X-rays, electromagnetic detection [1], eddy current testing [2], ultrasonic testing [3] and so on. Laser ultrasonic technology [4–7], as a widely used technique, has a good performance. Usually, surface acoustic wave detection method (including the pulsed echo [8] and pitch-catch method [9]) is sensitive to the surface and sub-surface damages and is an ideal way.

Laser ultrasonic imaging technology has proved to be an efficient way to detect cracks, which has many advantages over conventional ultrasound technology, such as being noncontact, easy to focus on, realizing fast scanning imaging and so on. Some scholars [10,11] adopt laser ultrasonic wave propagation imaging technology to visualize ultrasonic wave propagation, which can effectively detect the position of surface defects. Some other scholars [12–15] proposed methods for enhancing the visibility of the ultrasonic wave propagation images, which is to achieve the purpose of quantitative defect detection. Jia et al. [16] proposed the scanning heating laser source technique to analyze the frequency characteristics of ultrasonic waves. The results show that the frequency domain analysis can detect surface cracks. These methods only take surface acoustic wave to detect cracks; however, a method of detecting surface defects is put forward by using the longitudinal acoustic waves. According to the amplitude of the p-waves change at the propagation of surface defects at time of the maximum forward amplitude of the once P-waves at the position of damages arrived at the receiver, and analyze the B-scans of the time-domain data (*X*-axis or *Y*-axis) as the laser beam is scanned over the specimen with the damage or no defects. The P-waves propagation image at damage area demonstrates that the information of the surface damage can be efficiently evaluated.

In this study, we proposed a laser ultrasonic imaging method to detect surface damage in time domain for longitudinal acoustic waves by a laser ultrasonic technique. A laser ultrasonic system is developed, and typical B-scan time imaging of surface damage is realized. The P-waves propagation image at 1.5 μs demonstrates that the sizes, location and shape of the surface damage can be efficiently estimated. The outline of this research is as follows: Section 2 briefly describes the laser ultrasonic technique and the sketch for imaging method. The experimental results and discussion are shown in Section 3. Finally, Section 4 presents concluding remarks.

* Corresponding author.
E-mail address: 270401671@qq.com (W. Zeng).

http://dx.doi.org/10.1016/j.ijleo.2015.09.175
0030-4026/

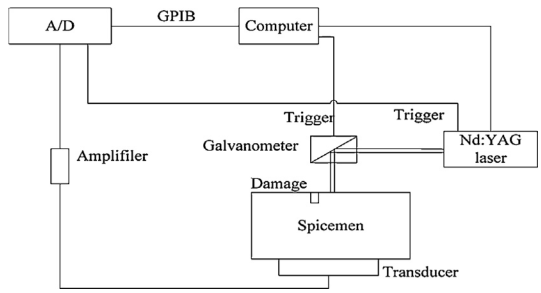

Fig. 1. Experimental laser ultrasonic inspection setup.

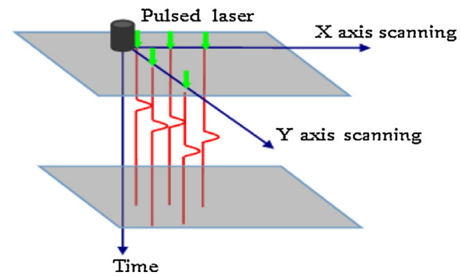

Fig. 3. The sketch for imaging method.

2. Experimental system and methods

Fig. 1 illustrates the diagram of the experimental setup. A Q-switched Nd:YAG laser (DAWA-200) with a wavelength of 1064 nm, a maximum pulse duration of 8 ns and a repetition rate of 100 Hz was used to excite ultrasonic waves. The diameter of the incident laser beam is less than 0.1 mm. The longitudinal waves were detected by an ultrasound receiver (the resonance frequency of 2.5 MHz). The shape of the receiver was a circular, 2 cm in diameter. The laser source was scanned by using the galvanometer. In order to analyze the signal efficiently, we used an amplifier to improve the signals amplitude and the signals were digitized with a sampling frequency of 25 MHz. In the excitation process, the laser energy with 15 mW output power is below the injury threshold of the specimen.

The austenitic stainless steel plate with a surface damage size of 2 mm × 2 mm × 2 mm was used by the laser ultrasonic inspection system, are shown in Fig. 1. The thickness of the austenitic stainless steel plate is 12 mm. The pitch of the scanning was 0.2 mm and the scan length was 10 mm, as shown in Table 1. In the received signal process, a 1–4 MHz bandpass filter was used to enhance the signal-to-noise ratio (SNR). The excitation points are at one side of the surface crack, the transducer was at the other side of the surface crack, are shown in Fig. 2.

The laser ultrasonic inspection system collects 2601 waveforms by the transducer after completion of a scan. The collected signals pile up into a data cube in different directions (X, Y, t), as shown in Fig. 3. According to the reciprocal theorem, we could select the longitude wave propagation images at the time of P-waves reached at the receiver generated by laser excited at the damage regions to detect the surface damage.

Table 1
The parameters used in the experimental system.

Material	Thick	Condition (length × width × depth)	Scanning length	The pitch of the scanning length
The austenitic stainless steel	12 mm	A surface hole flaw size of (2 mm × 2 mm × 2 mm)	10 mm × 10 mm	0.2 mm

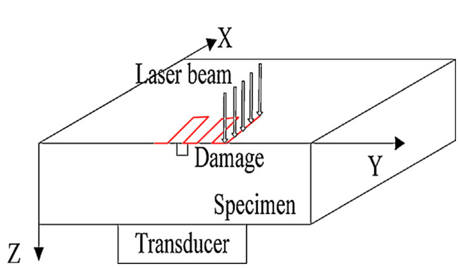

Fig. 2. Schematic diagram of detection the surface cracks.

3. Experimental results and discussion

Fig. 4 illustrates the typical waveform detected by the receiver. The once p-waves and the secondary p-waves were shown in Fig. 4. The experiment results illustrate that the amplitude of the longitudinal acoustic waves at different distances away from the surface crack. When the received signals at the excitation point (Y = 2 mm) are almost coincided with that of the laser excitation point (Y = 8 mm). However, when the laser excitation point (Y = 6 mm) is at the position of surface crack, the amplitude of the received p-waves are greater than that of the laser excitation point (Y = 2 mm or Y = 8 mm) and the arrival time of the P-waves is significantly ahead due to the propagation distance decrease. So we could conclude that the maximum forward amplitude of the P-waves produced at the position of the cracks is greater than that of the P-waves produced at other places. Fig. 3 clearly shows the maximum forward amplitude of the P-waves at the excitation point (Y = 6 mm) arrived to the receiver at 1.5 μs, in order to analysis of the changes with the amplitude of the once p-waves along the scanning area (X-axis or Y-axis), we would select the amplitude changes along the X-axis or Y-axis at 1.5 μs.

Laser ultrasonic evaluation image of 1-D in the austenitic stainless steel with no damage and damage are presented in Fig. 5(a) and (b), as can be seen that the once p-waves and secondary p-waves can be clearly measured by this technique. When the laser scanned over the specimen with no damage, the P-wave signals and the echo signals reached the transducer at 2 μs and 6 μs respectively, are depicted in Fig. 5(a). As can be seen from Fig. 5(a), the interval time between the two longitudinal waves was about 4.2 μs. The distances between the two longitudinal waves is twice the thickness of the sample, according to the relationship between distance and velocity of the ultrasonic wave propagation, we could use this method to calculate velocity of the p-waves and the depth of the damage.

$$V = \frac{2H}{4.2} = \frac{24}{4.2} = 5714\,\text{m/s}, \quad \text{Depth} = Vt = \frac{24}{4.2} \times 0.4 = 2.28\,\text{mm}$$

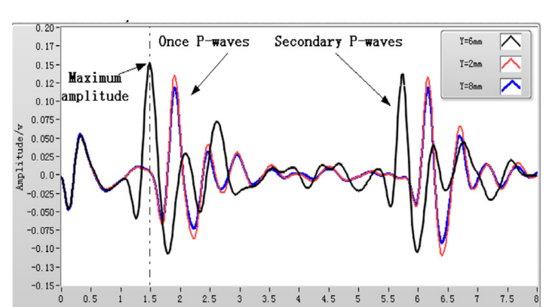

Fig. 4. The P-wave signals at the excitation points (Y = 2 mm, Y = 6 mm and Y = 8 mm).