Application of Laser Polishing in Laser Ultrasound Detection

He jianzong¹, He wen¹, Yang ting¹, He haohui¹, Yuan jinjing¹,², Yuan ling³, Lu jian³, Zhang hongchao ³*

¹ Dongguan Power Supply Bureau of Guangdong Power Grid Co., Ltd, Dongguan, China
² Guangdong Power Grid Corporation, Dongguan, China
³ Department of Information Physics and Engineering, Faculty of Science, Nanjing University of Science and Technology, Nanjing China
* hongchao@njust.edu.cn

Abstract. For issues that the low sensitivity of laser ultrasonic optical detection on rough sample surface, and even cannot obtain useful signal, this paper proposes a method of local polishing of laser detection point to improve the finish of the sample surface. And then improve the sensitivity of laser ultrasonic optical detection method. The Experimental system was established base on optical deflection method combined with laser polishing to verify the effectiveness of this method. The results show that local laser polishing can improve the light reflectivity of the detection point on the sample surface. And then the laser ultrasonic detection light deflection method can be applied to the rough surface. Local laser polishing has a high efficiency, while the detection of samples with minimal impact, especially suitable for rough industrial sample surface, this method further expands the scope of laser ultrasound application.

1. Introduction
Laser ultrasound is a non-contact, high-precision, non-injury new ultrasonic detection technology. It uses laser pulses to excite ultrasonic waves in the workpiece and continuous laser beams to detect the propagation of ultrasonic waves, thus obtaining defects in the workpiece. This technology combines the high accuracy of ultrasonic detection and the advantages of optical detection non-contact, high sensitivity (sub-nanoscale) and high detection bandwidth (GHz) [1]. At present, the technology has been widely used in the detection of surface defects in metal materials [2-4], the detection of elastic constants [5,6], the on-line detection of steel pipe thickness [7], the detection of de-adhesive defects of resin-based composite components of aircraft [8], and the maintenance of nuclear power plants [9].

The best detection method for laser ultrasound is optical detection. Optical detection is non-contact and does not interfere with the ultrasonic field to be tested, and the detection point can move quickly with a high spatial resolution. In addition, optical detection has a wide band. However, optical detection technology also has an obvious disadvantage. When the scattering of an object is very serious, its sensitivity is generally reduced by at least one order of magnitude [10]. For example, optical deflection is used in ultrasonic and laser ultrasound detection, but its disadvantage is that it requires mirror reflection. Many of the sample surfaces in the industry are not mirrored and cannot be detected with optical deflection method, limiting the range of applications of optical deflection method in the industrial applications.
Laser polishing, as a new processing technology, has the advantages of high efficiency and high flexibility. It has been favored by many scholars and research institutions. It acts through a focused laser beam on a rough original metal surface, causing melting and evaporation of convex thin layer on metal surface [11]. Melted material, due to the surface tension of the material itself and the action of gravity flow, fill the metal surface depression and coagulation, and eventually obtain the ideal polishing material surface. Through the control of the laser, the output energy at laser polishing is very small in the thickness of the metal material, only micron thickness of the material layer. Therefore, it will not cause a large area of rough surface when the general laser beam processing metal [12].

In order to make the optical deflection method can be used for laser ultrasonic testing of rough surface samples, laser polishing method was used to treat the surface of the sample before the testing. In this paper, in order to verify the validity of the method, a tin lead alloy sample with cracks and rough surfaces was used. Tin lead alloy is widely used in high-voltage cable accessories sealing. However, there may be minor defects in lead products and affect the subsequent use of the product. Figure 1 shows an example of the lead seal failures due to the seal quality. The surface of the sample has high roughness.

![Failed lead seal layer](image)

Figure 1. Failed lead seal layer

The detection point for laser ultrasound diagnosis was treated by laser polishing to improve local finish, and then laser ultrasound with optical deflection method was used to test the sample.

2. Experiment

The experimental device used is shown in Figure 2. The optical deflection is used to detect laser ultrasound. Before the testing, the detection point is local polished by the Nd:YAG laser to improve the finish of the samples surface.

![Schematic diagram of experimental system](image)

Figure 2. Schematic diagram of experimental system. OSC = Oscilloscope, BD = Balanced detector, 1/2λ = Half-wave plate, 1/4λ = Quarter wave plate, DSM= A pair of D-shaped mirrors, L= Lens, M = Mirror, BS = Beam splitter, PBS = Polarizing beam splitter, GM= Galvanometer scanner, D= Pin detector.
The Nd:YAG laser was used to excite laser ultrasound with wavelength of 1064nm, pulse width 7ns, repeat frequency 10Hz, and with a maximum energy of about 200mJ. The output energy of the laser is controlled by the computer. The excitation laser beam direction is controlled by the galvanometer scanner GM. The laser pulse was focused on the sample surface by the F-Theta lens L1 with a focus length 100mm to excite laser ultrasound. The galvanometer scanner GM is controlled by a computer and can be scanned in 2 dimensions (2D) for the excitation source. A small amount of laser is splitted by beam splitter BS to the photoelectric probe D for triggering the oscilloscope OSC. The OSC was used to display and store the laser ultrasonic signal. The sample is tin lead alloy with 10mm thick and a crack in the tin lead alloy surface.

Light deflection method is used to detect the laser ultrasound, as shown in Figure 2. The probe laser is He-Ne laser with 632.8nm wavelength. The propagation direction of the ultrasonic wave is perpendicular to the incident plane of the probe light. The intensity of the two beams arriving at the photosensitive surface of the balance receiver BD is the same by adjusting the two D-shaped mirror DSM. And the output signal is 0. When the ultrasonic signal passes through the detection spot area, the fluctuation of the sample surface will cause a small deviation of the reflected beam reflection angle. As a result, the relative intensity of the two beams received by the balance receiver is changed, and the output signal of the balance receiver is also changed, so as to realize the detection of ultrasonic signal.

Before the laser ultrasound is excited, the galvanometer is controlled by computer to make the nanosecond laser coincide with the detection point. Then, the detection points are polished by nanosecond laser with 15 pulses. Due to the local melting of the detection point, the detection point becomes smooth, thus improving its reflection signal, making it suitable for the detection of light deflection method.

3. Results and analysis

3.1. Laser polishing effect of sample

Figure 3 (a) shows the distribution of the light on the white screen reflected by the sample before and after laser polishing. Before laser polishing, due to the high roughness of the sample surface, the reflected light forms speckles, and the distribution range is very large, so it cannot be detected by light deflection method. Figure 3 (b) shows that reflected light distribution that the detection point was polished by laser. It can be seen from the figure that the reflection of the sample to the probe light is obviously improved. Although the reflected light is partially scattered, the energy has been relatively concentrated. Then the deflection method can be used to detect laser ultrasound.

![Figure 3](image-url)
3.2. Results and discussion

Figure 4(a) shows a microscopic image of cracks on the surface of the sample. Figure 4(b) shows the laser ultrasonic signal obtained by laser local polishing on rough surface, and the detection distances are about 10mm. The detection position and excitation position are located on the opposite side of the crack. From the figure, it is clear to distinguish the transmits Rayleigh wave tR and the Rayleigh wave tL-R converted from the longitudinal wave through the crack.

![Microscopic image of cracks](image1)

![Laser ultrasonic signal](image2)

Figure 4. (a) microscopic image of cracks on the surface of the sample. (b) Typical laser ultrasonic signal obtained by the experiment.

In order to verify the detection ability of sample cracks based on laser polishing, the sample is detected by scanning laser source method. In Figure 1, the detection point is fixed and the sample is scanned by the galvanometer scanner GM controlling excitation point. The results of the experiment obtained by the scan are shown in Figure 5. In the figure, R is the Rayleigh wave that arrives directly. rL-R is a Rayleigh wave that is converted by crack reflection. rR is a Rayleigh wave reflected by a crack. tR is the transmitted Rayleigh wave. tL-R is a Rayleigh wave formed by a crack-transmitted longitudinal wave pattern conversion.

![Time-domain B-scan diagram](image3)

Figure 5. Time-domain B-scan diagram obtained by the scanning laser source method.

From Figure 5 the direct Rayleigh wave signals R and reflective Rayleigh wave rR can be observed in the figure as the excitation source approaches the surface crack. Due to the presence of
cracks, a part of the surface longitudinal wave is transformed into Rayleigh wave rL-R. When the excitation source is scanned to the crack position, rR and rL-R disappear. As the scan continued, the transmitted Rayleigh wave signal tR and the transmitted mode conversion of Rayleigh wave tL-R began to be observed. The scan results clearly show the location of the surface crack. The crack reflects a portion of Rayleigh waves and causes a partial reflection and transmission of longitudinal wave to occur mode conversion.

By scanning the laser source, the exact position of cracks in the surface of the sample can be effectively detected. For rough samples, light deflection could not be used to achieve light detection in the past. By introducing laser polishing technology, sample testing can be achieved. In fact, using this method can also effectively improve the signal-to-noise ratio (SNR) of other optical detection methods, such as signal ratio based on Doppler interference test technology.

4. Conclusion
In this paper, a laser ultrasonic testing technology based on local laser polishing is proposed, which is verified by the experiment, and good results are obtained. The optical deflection method which cannot be used for rough surface can also obtain good laser ultrasonic signal by our method. This method provides a new way for the optical detection of laser ultrasonic. However, how to achieve a better polishing effect for the lead surface needs to be further studied on the types and parameters of the polishing laser, so as to make the detection point as close as possible to the mirror surface and further improve the detection effect of light deflection.

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