Overview of Laser-Based Inspection Technology

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Abstract. High-precision detection of structural state information and long-term monitoring of its operation process are the basic tasks that support the assessment of safety and reliability. Compared with methods such as sampling and testing, nondestructive testing does not damage the structural integrity, which has been the focus of research in recent years. Based on the demand for structural condition monitoring in the engineering field, this article has combed traditional non-contact monitoring technologies such as air-coupled ultrasound, and analyzed its working mode, technical characteristics, and application characteristics; around the non-contact characteristics of laser ultrasound technology, its excitation effect, Feedback picking, etc. were discussed. Finally, combing the technical characteristics and application basics, some suggestions for follow-up key research are put forward.

Keywords: structural status, non-destructive monitoring, non-contact, laser ultrasound, development suggestions

1. Introduction
Non-destructive testing of the state is an important means of obtaining state information. Generally, the response of the structure under certain excitation is picked up by a dedicated sensor, and specific information is obtained through correlation calculation; compared with sampling testing and other methods, it supports repeated sampling without damaging the structure Integrity. According to the range of response coverage, NDT can be divided into area projection type and volume transmission type; according to the excitation action range, it can be divided into surface response and volume response; according to the sensor layout requirements, it can be divided into contact type and non-contact type.

The state monitoring is based on the state detection technology, and the state analysis is performed on the target through the detection resolution ability, performance stability ability, and dynamic adaptability under long-term constraints. At present, the state monitoring technology for bonding structures can be divided into contact methods such as patch-type strain arrays, electromechanical impedance analysis, wet-coupled ultrasonic analysis, and non-contact methods such as air-coupled ultrasonic analysis and infrared thermal imaging analysis; The advancement of non-contact monitoring technology for multilayer materials and bonding structures has been a research hotspot in recent years.

2. Development status analysis of application technology
2.1 Current status and development trend of traditional non-contact monitoring methods
(1) Air coupled ultrasound analysis
Air-coupled ultrasonic analysis uses air as the coupling medium to avoid the introduction of coupling agents such as water and oil by conventional ultrasonic testing. It is suitable for objects that prohibit the contact of tripartite media such as aerospace structures and lithium batteries. This method uses piezoelectric material as the transducing material, with a frequency between 20kHz and 100kHz, excited by a high-voltage pulse signal, and received by a low-frequency low-noise pre-amplifier to achieve the goal of improving the efficiency of transduction and nondestructive testing.

Compared with traditional ultrasonic analysis, the use of air-coupled ultrasonic transducers to excite and sense ultrasonic waves achieves non-contact detection; in addition, the main advantages of this method are high detection resolution, easy automation, and suitability for in-situ detection. The disadvantage is that it is necessary to keep the distance between the sensor and the structure close, and it is impossible to achieve long-distance measurement.

(2) Infrared thermal imaging analysis

Infrared thermal imaging analysis measures the energy flow inside the object through the analysis of infrared radiation, and determines the correlation between the infrared signal and the defect: the infrared radiation of the damaged area and the healthy area in the heated structure is different, and the detected difference signal is digitized. The processing further realizes the visualization of the infrared band signal to judge the defects inside the test piece.

The innovation of infrared thermal imaging analysis lies in the use of infrared temperature measurement, which does not contact the measured object and does not destroy the temperature field. It reflects the two-dimensional temperature field distribution of the object intuitively and accurately in the form of thermal image, so that the physical characteristics near the surface of the material is reflected by the change of its surface temperature.

In 1965, Sweden developed an infrared imaging device with a temperature measurement function, called a thermal imager; in 1978, Texas Instruments of the United States successfully developed the world's first uncooled infrared thermal imaging system; in the 1990s, the United States developed a new generation of focal plane thermal imaging cameras. With the development and application of focal plane thermal imaging cameras, infrared thermal wave technology has entered a stage of rapid development, and its importance in the field of non-destructive testing has gradually emerged. The British University of Bath, the British Nondestructive Testing Association, and the University of Stuttgart, Germany are all committed to the study of this technology, and are widely used in the detection of internal defects and bonding quality, impact damage detection, and skin riveting quality detection of aircraft composite materials[1].

Yao Zhongbo[2] summarized the pulse infrared thermal imaging technology, ultrasonic infrared thermal imaging technology and phase-locked infrared thermal imaging technology according to the different excitation sources, combed the technical characteristics of various methods, and analyzed the structure detection and complete equipment. A comparative analysis of applications such as testing was conducted. A lot of domestic work has been carried out on key technologies such as infrared thermal imaging signal processing[3], parameterization and test methods for imaging evaluation[4], and typical target infrared thermal imaging physical models[5].

Overall, the technology is simple to operate and can detect metallic and non-metallic materials. The detection results are intuitive and the detection speed is fast. It is suitable for the rapid detection of large parts; the shortcoming is that it is impossible to distinguish in-plane defects such as micro-cracks of small size. It also does not have the ability to identify deeper defects.

(3) Electronic speckle interference analysis

The electronic speckle interference analysis is developed from the double-beam speckle interference technology. It is a non-contact full-field real-time measurement technology that can measure small deformations on the surface of the object: using laser speckle as the carrier of the change information of the measured object field, using After the laser beam is irradiated on the measured object, the relevant fringes of the interference speckle field are generated to detect the phase change before and after the double beam wave, and then the displacement field change or deformation information on the surface of the measured object is solved.

Based on the method of combining electronic speckle interference and digital shear speckle interference, MaYinhang et al. analyzed and studied the vibration process of cantilever thin plate and
explored a method to obtain high-precision mode image[6]. Scholars such as Li Gang[7] built an experimental platform for measuring the thermal deformation of metals based on the principle of laser electron speckle interferometry, combined with digital image processing to obtain a three-dimensional graph of metal surface deformation; Improve the quality of speckle images. Yang Yinfei et al.[8] proceeded from the principle of measuring the residual stress by the blind hole method, replaced the strain flower of the blind hole method with an electronic speckle interference device, and established a method for solving the residual stress by measuring the residual deformation.

The main advantages of electronic speckle interference analysis are its high detection speed and high degree of automation, as well as its high measurement sensitivity. Similar to infrared thermal imaging analysis, the surface properties of the detected objects determine that this method is difficult to identify deep defects.

(4) Laser holographic analysis

Laser holographic non-destructive analysis has developed on the basis of holographic technology and has been applied earlier. This technology uses laser holographic interference to detect and measure the surface and internal defects of the object. The basic principle is: by applying a load to the object to be measured, the difference between the deformation amount of the defective part and other parts is used to form a holographic image to reflect the material and structure. Whether there is a defect inside.

The loading methods of laser holographic non-destructive analysis include acoustic loading, thermal loading, internal inflation method, surface vacuum method, and observation methods for the differential displacement of the object surface include real-time method, double exposure method, and time average method. Laser holographic nondestructive analysis has been well applied in the fields of tire quality inspection, composite materials and parts inspection.

Wang Yonghong et al. gave the process flow, process method and process specification of laser holographic detection by studying the displacement of laser holographic detection and the load theory of laser holographic detection, combined with the detection test, and milled the groove of the expansion section of a certain type of liquid rocket engine thrust chamber The non-destructive testing of the sandwich structure brazed joints[9]. Li Guancheng, Yu Yanchun and other application examples summarized the basis and development trend of laser holographic nondestructive testing technology, and pointed out that its application field expanded from engineering technology to medicine, art, decoration, anti-counterfeiting, packaging, printing, printing and dyeing, cross And marginal disciplines[10,11].

From the analysis and summary of the current situation, the laser holographic non-destructive analysis and detection system is complex, requires high skilled operation, and has strict requirements on vibration resistance, light avoidance and loading conditions.

(5) Optical three-dimensional tomography technology

In recent years, optical coherence tomography technology has developed rapidly due to its superior performance characteristics of non-invasive, non-contact, high resolution, non-destructive, and sensitivity. It has been widely used in biological tissue monitoring and detection, and has a micron-level resolution and imaging depth in millimeters.

Wang Ling, Zhu Hai long and others[12] developed a high-speed three-dimensional swept frequency optical coherence tomography (SS-OCT) imaging system; the system is based on fast frequency-swept laser technology, and the axial scanning rate can reach 50KHz, which can achieve realtime equal wave number Interferometric spectral signal sampling at intervals; the measured axial resolution of the system is 8.9µm, and the sensitivity remains above 100dB over the entire imaging depth range. Yu Xiaofeng and Ding Zhihua studied the fiber-optic optical coherence tomography system. Based on the Michelson interference principle and heterodyne detection method, a single-mode fiber-type optical coherence tomography method was established to construct the two-dimensional optics of living tissue under natural conditions. Coherent tomography images and three-dimensional optical coherence tomography images[13]. For the three-dimensional imaging technology of terahertz waves, Wang and Ye combed the basic principles and corresponding research progress, and analyzed the existing problems and development trends[14].

Due to the extremely limited penetration ability in composite materials, especially metals, in industrial applications, only the shape inspection of mechanical components and composite materials
can be achieved, and real-time monitoring of internal defects of mechanical components cannot be achieved.

2.2 Current status and development trend of laser ultrasonic monitoring methods
Laser ultrasonic technology is a new technology of non-destructive testing developed in the mid-1970s. It uses laser pulses to irradiate the surface of the sample to excite ultrasonic waves and detect the ultrasonic waves. This method has the advantages of non-contact detection, high accuracy and sensitivity, and is suitable for special environments such as high temperature and high pressure.

At present, laser ultrasound is widely used in the field of non-destructive testing. Laser ultrasound testing has been used abroad for the detection of aircraft composite materials and the online detection of hot steel. In chemical vapor deposition, physical vapor deposition, plasma sputtering and other high temperatures the real-time detection of film thickness during the coating process was also studied.

(1) Classification of excitation effects
According to the power and effect of the excitation light source, the types of laser ultrasonic excitation are divided into thermoelastic effect and ablation effect.

When the laser power is small, the laser will cause a temperature difference of the structure under test due to local heating, forming a thermoelastic effect and exciting the structure ultrasonic wave; when the laser power is large, an ablation effect will occur, and the ablated sputtered substance exerts a force on the precursor 2. Generate local stress.

Song Yanxing and Feng Qibo studied the effect of laser parameters on the laser-excited ultrasonic signal, and applied pulsed laser with light attenuation structure to experimentally analyze the effect of laser pulse energy and irradiation spot size on the excited ultrasonic signal[15]. Li Haiyang analyzed the interaction between laser-excited ultrasound and surface cracks on metal materials at different tilt angles, and proposed a method to estimate the tilt angle of surface cracks based on the spectrum of the reflected surface signal and the transmitted surface signal of defects[16]. Song Yanxing, Wang Jing et al[17] studied the influence of laser parameters and laser ultrasonic detection methods on ultrasonic signals, and pointed out that the incident laser parameters will affect the amplitude of the excited ultrasound, and the optical detection method based on double-wave mixed interference can obtain a more complete Ultrasonic information.

(2) Development of feedback pickup
In the non-contact incident excitation mode, the signal pick-up of laser ultrasound has successively experienced the stages of pasting sensors and medium coupling. The contact problem of feedback acquisition has not been solved, which limits its in-situ and engineering practicality.

Since 2016, the Massachusetts Institute of Technology has successively carried out research on laser radiation technology in the degradation of material irradiation.

3. Development trend analysis
There are great technical difficulties in condition monitoring:

1) There are a large number of sensitive materials, and there are strict restrictions on the monitoring medium and excitation mode. The monitoring process does not allow high energy and strong excitation. There is a strong demand for highly sensitive and non-contact monitoring technology;

2) The structure is compact and foreign objects are strictly prohibited. The traditional buried and contact monitoring methods cannot be directly used;

3) The environmental temperature, mechanical stress and other sections of storage and transportation are complicated, which may lead to complex defects such as micro cracks, mesopores, and macro-disengagement in the bonded structure. It is more difficult for the monitoring technology to identify the multi-scale features of the structural state.

On the whole, it should be based on the existing laserultrasonic guided wave non-contact excitation:

1) Facing the structural characteristics, physical properties, service environment and typical defects of the target structure, study the dynamic response process inside the structure under the combination of ultrasonic types and wave parameters, and select the ultrasonic category and optimize the fluctuation parameters around the characteristic response.
2) Focus on the target ultrasound type and fluctuation parameters, study and establish a method for controlling the laser excitation process, and optimize the wavelength and power-time distribution of the incident laser.

3) Based on application scenarios, develop non-contact pick-up technology of feedback signals, solve the problem of physical contact at the end, support non-contact monitoring and its large-scale coverage.

4) Comprehensive use of numerical simulation and experimental calibration work, focusing on the diversity and complexity of typical defects, establishing a correlation model of feedback signals and typical defects to improve detection resolution and monitoring sensitivity.

5) In view of the limitations of non-visual technology of ultrasonic guided wave monitoring, develop quantitative identification and quantitative characterization technology of structural state.

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