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Remote inspection of surface cracks in metallic structures with fiber-guided laser array spots thermography

Jinxing Qiu [a], Cuixiang Pei [a,*], Haochen Liu [a], Zhenmao Chen [a,**], Kazuyuki Demachi [b]

[a] Shaanxi Engineering Research Center of NDT and Structural Integrity Evaluation, State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an 710049, China

[b] School of Engineering, The University of Tokyo, Tokyo 113-0032, Japan

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ABSTRACT

In this work, a fiber-guided laser array spots thermography (LAST) system with good flexibility is proposed for the inspection of surface cracks in metallic structural objects with difficult access. To generate an array of laser spots on the target surface, an optical head with fiber delivery is designed and fabricated at first, which has good adaptability and robustness. Second, a numerical simulation model is developed to optimize the spatial distribution of the laser spots. In addition, an improved image processing method with use of multiple background free images is developed to enhance the crack detectability from the LAST images. Finally, cracks of different types in stainless steel specimens are successfully detected from the thermal images obtained using the fiber-guided LAST system.

1. Introduction

The inspection of surface cracks caused by fatigue or stress corrosion cracking (SCC) is of great importance to ensure the safety of metallic structures [1,2]. Much attention has been paid to the nondestructive testing (NDT) or evaluation of surface cracks. Until now, researches and applications are mainly concentrated on the conventional NDT methods such as the eddy current testing (ECT), the ultrasonic testing (UT), and the dye penetrant inspection (DPI) [3–8]. However, these techniques cannot be applied remotely, which makes the inspection low efficiency, and even inapplicable for some inspection targets which have no enough space to handle the NDT transducers.

Infrared thermography (IRT) is a noncontact NDT technique and normally uses lamp, laser, eddy current, or ultrasonic wave as heating sources. The laser spot thermography (LST) is a new IRT method for the inspection of surface cracks. The LST method uses a laser to generate a highly localized heating spot near by the crack and an infrared camera to detect the perturbation of the round lateral heat flow to reveal the crack information [9–14]. However, as the current LST method uses a point source to scan over the inspection area, the inspection time can be very long and the processing data are very large especially for a large structure. In order to improve the inspection efficiency and simplify the testing system, some new LST methods have been developed. An and Yang et al. have studied the inspection of surface cracks in semiconductor chips by using line laser and multi-spot laser sources, respectively [15,16]. Especially, the use of multi-spot laser source can significantly improve the inspection efficiency and reduce the data processing. However, the multi-spot laser thermography system introduced in Ref. [16] may be not applicable for some cases, because the detection target may be in a narrow space. In such a case, not like on the experimental table, it is difficult to set the light path to the target position precisely with the optical lens.

To solve this problem, an improvement of the multi-spot laser thermography method with use of the fiber delivery is proposed to improve the adaptability and robustness of the multi-spot LST in this work. An optical head of small size connected with the optical fiber is specially designed to generate an array of laser spots on the target surface from the single laser beam. To optimize the optical components, a 3D numerical simulation is conducted for analyzing the heat flow from the laser array spots on the metallic surface with a crack. Furthermore, an improved image processing method based on the holder exponent analysis and the multiple images superposition is developed to reduce the surface-reflected background noise and to visualize the crack instantaneously in single measurement without scanning the laser. Finally, the developed fiber-guided laser array spots thermography (LAST) system is applied to inspect cracks of different types (including electrical discharge

* Corresponding author. No. 28, West Xianning Road, Xi'an, China.
** Corresponding author. No. 28, West Xianning Road, Xi'an, China.
E-mail addresses: pei.cx@mail.xjtu.edu.cn (C. Pei), chenzm@mail.xjtu.edu.cn (Z. Chen).

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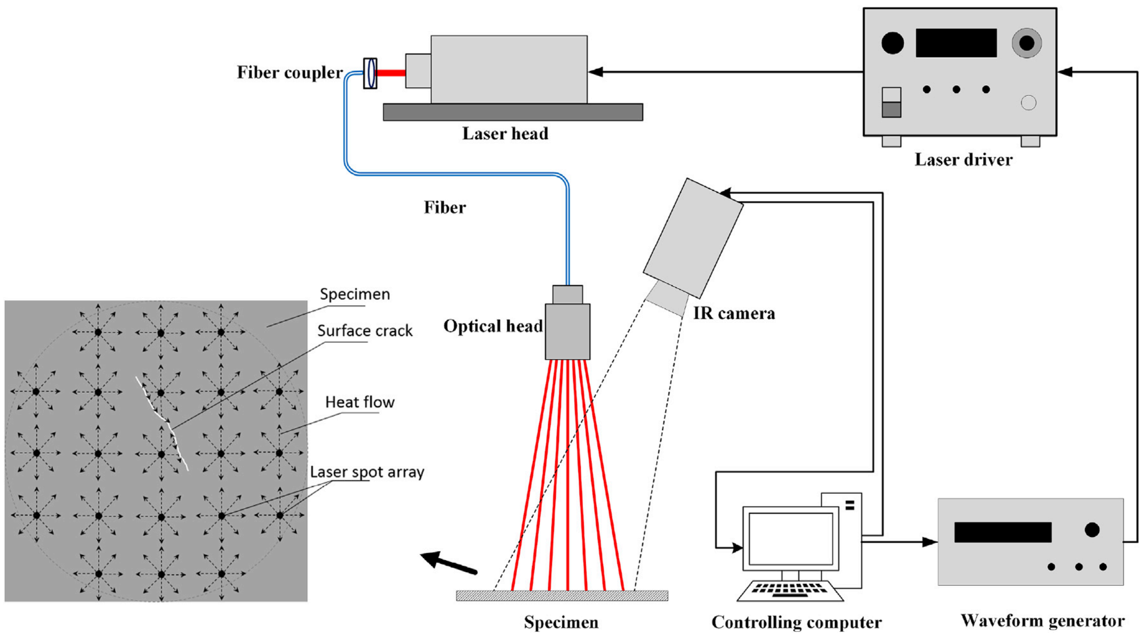

Fig. 1. Schematic diagram of the proposed fiber-guided LAST system and the basic principle for crack inspection.

machining crack, fatigue crack and stress corrosion crack) in metallic specimens to demonstrate its feasibility.

2. Development of the fiber-guided LAST system

2.1. Overall system design and setup

The schematic diagram of the fiber-guided LAST system for surface crack inspection is shown in Fig. 1. The system is composed of excitation, sensing, data processing and control units. The excitation unit includes an arbitrary waveform generator (AWG), a laser driver, a CW laser head, a fiber coupler, an optical fiber and a specially designed optical head. The CW laser used in the system has a wavelength of 1064 nm and a maximum power of 100 W. The modulated laser beam is coupled into the optical fiber and is guided and transmitted to the target area. The optical head connected with the fiber is composed of two plano-convex lenses (PCL) and a diffractive optical element (DOE). With the optical head, the laser beam coming out from the fiber is collimated, split and focused into 9×9 laser array spots on the target surface. The sensing, data processing and control units comprise an IR camera and a personal computer (including data acquisition and processing software). The IR camera used here has a noise equivalent temperature difference of 50 mK, a resolution of 320×280 pixels at a sampling rate of 8.5 Hz, and a spectral range of 7.5–14 μm.

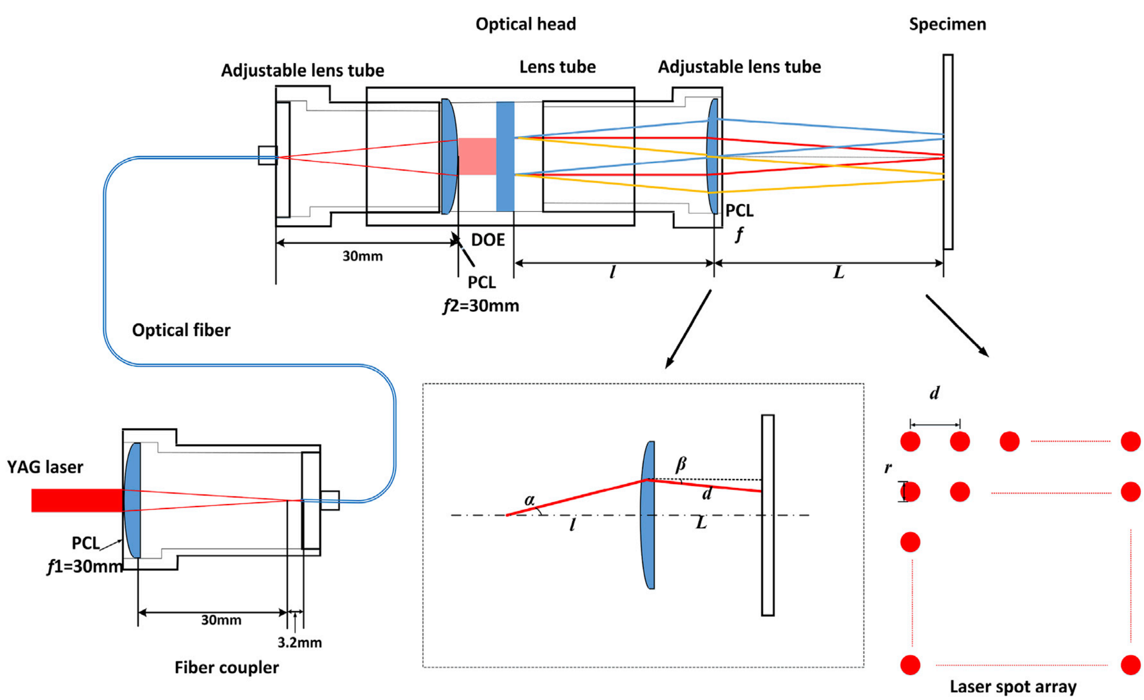

Fig. 2. Schematic diagram of the optical components for laser beam splitting with fiber delivery.