NDT&E International 58 (2013) 72–77

Contents lists available at SciVerse ScienceDirect

NDT&E International

journal homepage: www.elsevier.com/locate/ndteint

LED optical excitation for the long pulse and lock-in thermographic techniques

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ARTICLE INFO

Article history:
Received 23 December 2012
Received in revised form
25 April 2013
Accepted 26 April 2013
Available online 6 May 2013

Keywords:
Infrared thermography
Thermal imaging
Thermal wave methods

ABSTRACT

High power light emitting diode (LED) arrays have been investigated as excitation sources for long pulse and lock-in thermography. Images of artificial defects in a carbon fibre reinforced plastic (CFRP) composite sample are compared, by image contrast signal-to-noise ratio estimates, with those obtained using conventional incandescent flash and lock-in excitation sources. The LED arrays had to be mounted on heat sinks with active cooling in to prevent them exceeding their thermal tolerance. Despite this cooling the LED arrays were still found to emit some IR radiation, although far less than conventional incandescent light sources.

1. Introduction

Pulsed transient thermography e.g. [1–3] and lock-in thermography e.g. [4,5] are the most commonly used thermographic NDT&E techniques. The two techniques are distinctly different but are used for very similar component/structure inspection applications. Their defect detection capabilities are similar, i.e. the detection and imaging of broadly planar defects lying a short distance below the surface, e.g. delaminations in composites or adhesion defects in surface coatings. For pulsed transient thermography, the surface of the part to be inspected is flash heated by one or more high energy optical flash lamps or long pulse heated for a number of seconds using high power incandescent lamps, whilst for lock-in thermography the surface is heated periodically by modulated high power incandescent lamps for periods that may last for hundreds of seconds.

The technique of pulsed transient thermography involves using a high intensity pulse of light to heat the surface of a test piece via the photothermal effect. Both very short duration (~1 ms) flashes and longer duration (seconds) pulses can be employed, depending on the sample thermal properties and defect depth.

Very short duration flashes are the preferred excitation method as sample thermal contrast caused by sub-surface defects is not obscured by the heat pulse. Depending on the sample thermal properties and defect depth, longer pulses (on the order of seconds) can also be employed. Long pulse testing has the advantage that the excitation sources are generally far simpler and cheaper than those required to generate fast flash excitation.

The test piece surface temperature is recorded by an infrared camera and computer system as it decays due to heat being conducted into the part after its deposition on the surface. Sub-surface defects reduce the conduction of heat away from the surface and therefore reduce the surface cooling rate compared to that occurring over non-defective regions. Consequently, a surface temperature contrast develops over a defect that can be used to detect a defective region. Alternatively, theoretical thermal decay predictions for defect free solids can be compared with the observed decay profiles to determine whether the sample contains sub-surface defects [6,7].

In lock-in thermography, the sample is heated periodically, typically using a number of sinusoidally modulated tungsten-halogen flood lamps. Thermal images of the sample are recorded throughout the heating period, which lasts for at least one full excitation cycle. The magnitude of the periodic temperature change at the surface and its phase with respect to the applied modulated heating is then extracted by post-processing the recorded image data. After post-processing, the result of a test consists of just two images—a magnitude and a phase image.

With conventional flash or long-pulse heating using flash tubes or incandescent lamps, the tube/lamps and shroud continue to emit IR radiation even after they have been switched off. This additional IR radiation is directly reflected or scattered into the camera, causing surface reflectivity differences to dominate the early-time thermographic images, and also provides additional heating to the surface, which makes it difficult to measure and use the cool-down behaviour at these early times.

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0963-8695/$ - see front matter
http://dx.doi.org/10.1016/j.ndteint.2013.04.009

For lock-in thermographic testing the reflected IR radiation produces a large in phase component which is combined by superposition with the useful out-of-phase signal produced by the sample internal structure and thereby significantly reduces the observed phase signal making it both more difficult to detect and rendering theoretical predictions very inaccurate [8–10].

Recent developments in light emitting diode (LED) technology have led to high power density LED units, which are comparable with incandescent lamps in terms of brightness while being more compact, having lower power consumption and producing little or no infra-red radiation.

Low power, compact and highly controllable LED arrays are potentially ideal for thermographic NDE applications due to their portability and ability to be used to inspect components with constrained access. The fact that LED arrays produce little or no IR radiation is also of particular interest for thermographic NDE.

This paper investigates the use of high power LED arrays for pulse and lock-in thermography. Long pulse LED excitation is compared with conventional flash thermographic excitation and square wave lock-in LED excitation is compared with conventional incandescent lamp lock-in excitation. An objective comparison is made of the signal to noise ratios (SNR) produced by the different techniques.

2. Test equipment

2.1. Test sample

Fig. 1 shows a diagram of the CFRP test sample used for this testing containing flat-bottomed back-drilled hole defects at depths ranging from 0.25 mm to 2.75 mm in steps of 0.25 mm. Only the 6 mm and 4 mm diameter defects were considered in this work.

2.2. IR camera equipment

For all testing a TWI ThermoScope system using an Indigo Merlin camera was used. The ThermoScope system is an integrated pulsed thermographic system employing a medium wavelength infrared camera and an integrated flash heating system which produces a pulse of light lasting ~3 ms with an electrical energy of approximately 2 kJ. The Indigo Merlin is an electrically cooled InSb Focal Plane Array (FPA) camera with 12-bit digital output and a resolution of 320 × 256 (width × height). The camera has a maximum framerate of 60 Hz and an NEdT of less than 25 mK (and typically < 18 mK) [11].

2.3. High power light emitting diode arrays

The LED arrays used in this work are 16 W units produced by Litewave Ltd. These are claimed to produce optical flux approximately equivalent to that produced by a 45 to 50 W incandescent Halogen lightbulb [12]. These units can be driven from a 12 V supply, which means their power supply can be made portable quite easily.

Fig. 2 shows a picture of a single LED array unit. The overall LED array unit size is 17.5 mm × 28 mm with a thickness of 1.4 mm. The LED emitter area in the centre measures 12 mm × 12 mm. The small size of these units is important both for potential use in confined areas and also in order to provide sufficiently high optical intensity and therefore photothermal heating of sample surfaces.

While LEDs are highly efficient and therefore produce little excess heat compared with incandescent light sources, it is recommended by the manufacturer that each LED array unit is mounted on a heat sink to ensure that when used they do not exceed their thermal tolerance limit of 120 °C. In the case of the testing reported in this paper, it was important to keep the temperature considerably lower than the thermal tolerance limit, and to disperse any excess heat away from the part being tested to ensure that no IR radiation would be generated by the LED array to interfere with the signal emitted by the test sample.

2.4. Lock-in testing

For the lock-in testing four LED arrays were employed with each LED array screwed down on an individual computer Central Processing Unit (CPU) heatsink with cooling fins and an attached fan in order to maintain a low operating temperature. Due to the wide beam angle of the LED arrays (~140°), plano-convex lenses were mounted above each array element and held in place using synthetic rubber putty to produce a beam angle of approximately 30° which could then be focused on the sample. Fig. 3 shows a picture of a single LED array attached to an aluminium heat-sink with a plano-convex lens attached to its front face.

A square-wave lock-in excitation signal was used instead of a sinusoid in order to simplify the control of the LED arrays at the expense of wasting some energy at harmonics of the lock-in frequency. For comparison, two 1 kW tungsten–halogen flood lamps were driven using a signal generator and amplifier to produce a sinusoidal temperature flux on the sample surface. Water screens were used with the flood lamps to ensure that direct IR produced by the lamps was removed. This would otherwise have interfered with the phase response of subsurface defects significantly reducing the observed surface phase response [8–10].

Fig. 4 shows the four LED arrays facing away from the camera with a gap in the centre where the IR camera would be placed. The cooling fans connected to the rear of the heat-sinks can be seen in this photograph, as can the large number of wires required to power the arrays and cooling fans.

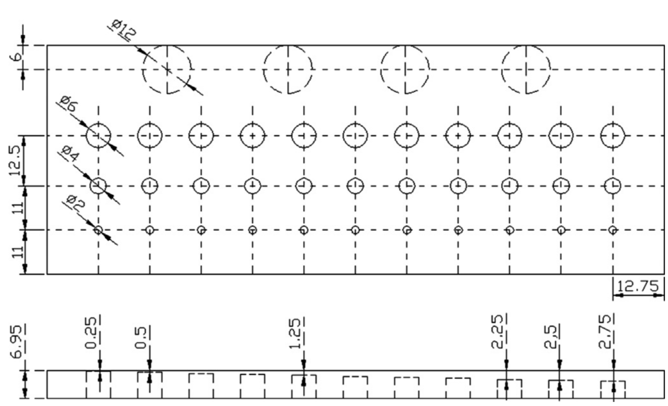

Fig. 1. CFRP composite test sample (all dimensions in mm).

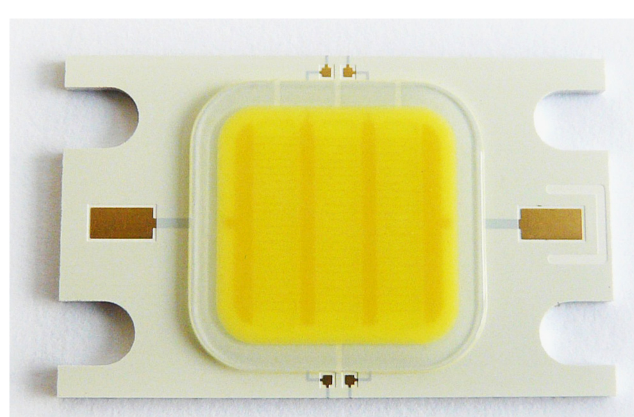

Fig. 2. Litewave LED array (image courtesy of Litewave Ltd.).