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A design of multi-mode excitation source for optical thermography nondestructive sensing

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ABSTRACT

Optical thermography is an important non-destructive testing (NDT) method which has been widely used in the fields of modern aerospace, renewable energy, nuclear industry, etc. The excitation source is a crucial device for the optical thermography system whose performance has a decisive effect on the detection results. Previous thermography NDT studies mainly focused on the physical mechanism, applications and signal processing algorithms. However, the design of the excitation source is rarely discussed. Due to the wide frequency range as well as the high power excitation requirements, it is a challenging task to develop a multi-mode excitation source for thermography NDT. This paper presents a novel design of the excitation source with a structure topology that combines the circuit with low frequency sinusoidal generation and a chopper circuit. It intimately satisfies the requirements of multiple-mode excitation for optical thermography. These include pulsed thermography (PT), lock-in thermography (LT), step heating thermography (ST), pulsed phase thermography (PPT), frequency modulated thermal wave imaging (FMTWI) and barker coded thermal wave imaging (BCTWI). The proposed topology, operating principle and the design procedure of the circuit have been investigated in details. A 2 kW prototype with a frequency range of 0.01 Hz–100 kHz has also been implemented. Validation of the proposed method has been undertaken to detect inner defects of both on a composite sample and a lead-steel sample with bonded structure.

1. Introduction

The excitation source has been widely used in the sensing and detection fields as a part of the system, such as laser detection [1], electromagnetic thermography testing [2], ultrasound inspection [3], and plasma detection [4]. The excitation sources can be implemented by utilizing the power electronics technology, such as AC-DC, DC-AC, DC-DC and AC-AC conversion. However, researchers in this field mainly concern in the performance index of power conversion, such as efficiency, power factor, ripple, and power density. This research directions include design topologies [5,6], control strategies [7–9] and new power electronic components [10,11]. Therefore, it is necessary to hybrid the requirements of the sensing and detection with the power electronics technology to design a functional excitation source for the specific diagnosis system.

Active infrared thermography (AIT) was developed to provide more accurate information by considering the amount of thermal radiation and heat transfer. Due to the different external excitation source in AIT, it can be divided into inductive thermography, optical thermography, vibro-thermograph, etc. [12]. Optical thermography has gained increasing attention because of its non-destructive imaging characteristics with high precision and sensitivity [13]. It has been applied to the defect inspection and evaluation of composite materials such as glass fiber reinforced polymers (GFRP), carbon fiber reinforced polymers (CFRP) and adhesive bonds [14–17]. Depending on the different heating excitation mode, it can be divided into pulsed thermography (PT), lock-in thermography (LT), step heating thermography (ST), pulsed phase thermography (PPT), frequency modulated thermal wave imaging (FMTWI), barker coded thermal wave imaging (BCTWI), etc. [24–31].

In PT, the sample surface is stimulated by a short pulse with a high power light lamp. The thermal wave propagates from the sample surface into the inner part through diffusion. The resultant sequence of infrared images has potential to indicate defects in the sample at different depths [18–21]. The method apart from requiring high power heat sources, has additional drawback of being sensitive to surface

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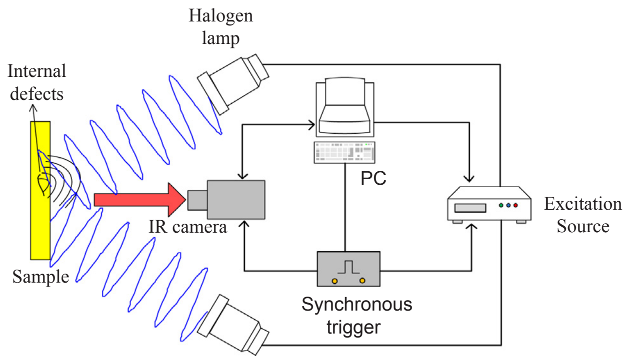

Fig. 1. Diagram of the optical thermography.

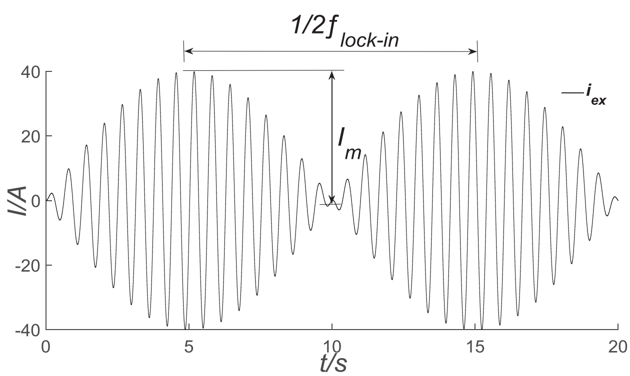

Fig. 2. Profile of the lock-in excitation current.

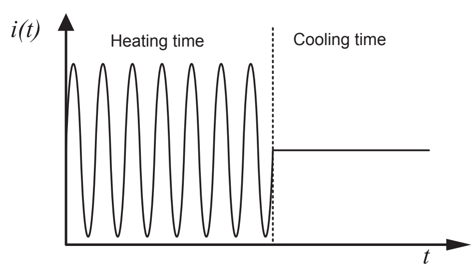

Fig. 3. Profile of the pulsed excitation current.

inhomogeneities. In LT, the sample is heated using a mono-frequency sinusoidal thermal excitation. The magnitude of the periodic temperature change at the surface and its phase with respect to the applied modulated heating is extracted by using post-processing algorithms for defect detection [22]. This method has advantages of better signal-to-noise (S/N) ratio and adjustable depth range for inner defect visualization. However, it demands a selection of a suitable frequency to avoid the blind frequencies and the repetitive experiments are required to resolve the defects location at different depths [23]. ST based on temporal temperature analysis caused by step excitation in time domain is similar to PT in heating excitation mode which has longer heating time. PPT is same to PT in heating excitation mode, where, an analysis is carried out by phase mode which has the merits of phase images obtained with LT [24]. In FMTWI, the sample is heated by using excitation source with a limited range of frequencies. This method attempts to overcome the drawbacks of LT [25–27]. In BCTWI, the sample is heated using a binary coded thermal excitation. This excitation method combines with correlation processing which can provides better detection capabilities and better depth resolution [28–30]. Those methods usually use flash lamps or halogen lamps as a heating source which are excited by an excitation source such as power amplifier with signal generator.

Previous studies mainly have been focused on the principles, various applications and signal processing algorithms [23–34] for optical thermography in NDT. However, the design of the excitation source is rarely discussed. Due to the requirements of wide frequency range (typically 0.01 Hz to several hundred kHz) and high power (typically hundreds of W to several kW), the design and the developing of the particular multi-modality excitation source for thermography is highly challenging. One promising approach is to utilize a high voltage linear amplifier, but the downside is its restriction by the gain bandwidth product (GBP) which can lead to a low efficiency [35]. In recent years, digital control power converters have been described as be able to offer a high capability to efficiently manage electrical energy as they are widely applied in industrial applications, electric traction systems, renewable energy systems, distributed generation, and automotive [36]. Thus, this paper proposes a structural design topology of a multi-mode excitation source with high performance under the framework of a digital control strategy. This paper presents the design of an excitation source with a maximum output power of 2.0 kW and a wider frequency band ranging from 0.01 Hz to 100 kHz which is used to drive the halogen lamps. The proposed topology, operating principle, and the design procedure of the circuit have been investigated. In addition, experimental validations been conducted to verify the proposed methodology.

The paper is organized as follows: Section 2 discusses the optical thermography characteristics, Section 3 describes the proposed solution and topology. Section 4 describes operating principle; Section 5 presents the experimental results and discussion. Finally, Section 6 concludes the work.

2. Optical thermography sensing

Fig. 1 shows the diagram of the optical thermography system. Halogen lamps or flash lamps are driven from pre-set current which is generated by excitation source. The incident light generates the heat on the sample and the heat diffuses in time. Defects such as cracks, debonds, delamination alters the heat diffusion and the progress is recorded by infrared (IR) camera. A synchronous trigger receives the “start” command from the PC and then triggers the IR camera and the excitation source to work synchronously. According to the different pre-

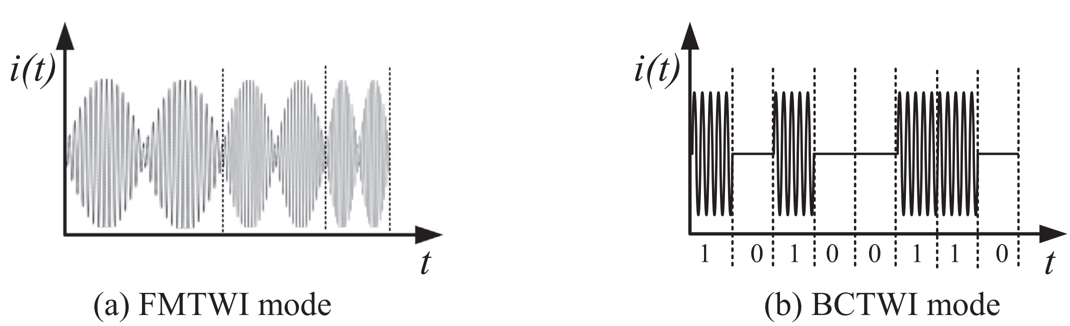

Fig. 4. Profile of the (a) FMTWI and (b) BCTWI excitation current.

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