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Evaluating a Custom-built LED-based Excitation Source for Lock-in Thermography

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Abstract

Active thermography comprises various methods of non-destructive testing. The response of a device under test to step or periodic excitation is evaluated. Commonly, powerful light sources are used for this purpose. For seamless integration into any measurement setup, a source should be adaptable to different requirements via multiple operation modes and interfaces. In addition to a powerful optical output, a good signal shape and response characteristic are desirable. In this work, a custom-built LED-based excitation source following these design principles is presented. The schematics are fully disclosed and its performance in active thermography applications is discussed.

1. Introduction

Active thermography is a technique where the principles of lock-in amplification and thermography are combined to create amplitude- and phase-images of thermal waves. The technique is typically used for defect detection and for the measurement of material parameters such as the thermal diffusivity or layer thickness. While some applications depend on internal heat sources such as vibro-thermography, for lock-in thermography, external sources are commonly used to excite thermal waves at the surface of the device under test. Typical sources include halogen lamps, spot-lasers [1], LEDs [2], and VCSEL [3]. Ideally, excitation sources for active thermography have a high power, a high dynamic range, and a fast response characteristic. Halogen lamps are powerful and relatively inexpensive sources, which can be easily integrated into a setup. Nevertheless, the maximum modulation frequency as well as the dynamic range are limited by the high thermal inertia of the halogen lamp. For accurate measurements, it is necessary that the emission of the excitation source does not lie within the spectral sensitivity range of the detection system. A good compromise with respect to price-to-performance ratio is the use of LEDs. While LEDs are not as bright as lasers, the output power can be controlled in a wide range via the driving current. However, the use of a conventional LED-based luminaire is often not practical. This is usually due to the restrictions of the included driver-circuit as well as the limited radiance.

In this work, a custom-built infrared LED-based excitation source as well as its driver circuit (Figure 1) are presented and evaluated in detail. The driver circuit (left) includes a digital and an analogue input to fully control the LED current and to produce arbitrary output signals. For some applications, it is useful to focus the optical power into an area which is smaller than the cross-section of the LED lenses array (middle). For this, a parabolic, 3D-printed reflector is designed (right).

Fig. 1. *(left) Driver circuit, (middle) lamp with lenses, (right) lamp with parabolic reflector.*

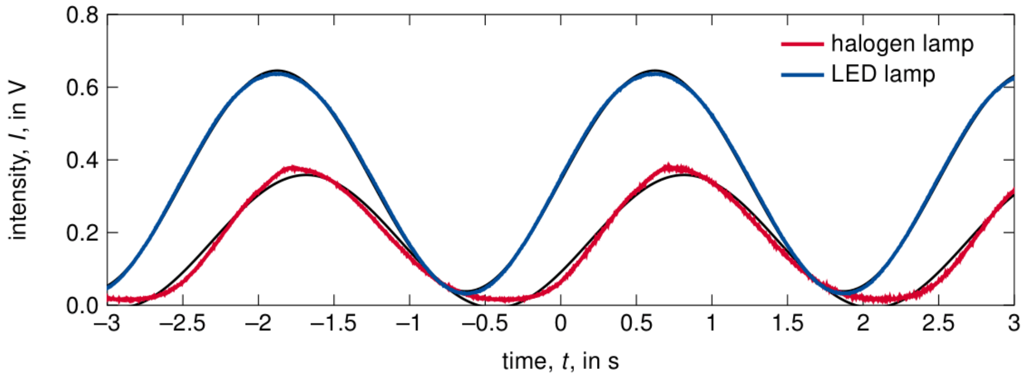

Fig. 2. *Signal form of the LED lamp and a halogen lamp at 0.4 Hz, including a least-squares sine wave approximation.*

2. Housing, infrared sources, and driver circuit

The housing features a ventilated central cooling channel for heat dissipation. The channel splits the housing into two chambers and offers two surfaces, which are thermally well-connected to the ambient. In the front chamber, the LEDs are mounted on an aluminium substrate PCB (printed circuit board). The driver circuit is located in the back chamber. The circuit layout is provided as part of this work.

Table 1. *Minimum specifications of the LEDs and the driver circuit.*

Parameter	Symbol	Value
LED forward voltage	U_F	42 V
LED forward current	I_F	3 A
Central wavelength		850 nm
Radiant flux	Φ_e	55 W
Voltage level, analogue input		3.3 V
Voltage level, digital input		5 V

Parameter	Symbol	Value
Maximum supported power	P_max	440 W
Maximum frequency	f_max	1 kHz
Amplitude response	$G(f)$	±1 dB
Phase response	$\varphi(f)$	1°
Rise time, fall time	t_r, t_f	10 µs
Jitter	A_J	±5 µs

Placing the LEDs on a 14 mm grid allows placing 36 LEDs inside the housing in a 6×6 layout. Here, infrared LEDs of the type OSLON® Black SFH4715 AS from OSRAM Opto Semiconductors are used. At a rated forward current of 1 A, this single-emitter LED emits an optical power of 1.53 W at a nominal wavelength of 850 nm. Using 36 LEDs, the resulting optical power amounts to 55 W.

3. Evaluation

This work is focused on a performance evaluation of a custom-built LED lamp. It is investigated for its radiometric properties and compared to the performance of other sources such as halogen lamps. In addition, the amplitude and phase response are measured. In Figure 2, a time sequence of its emission intensity is shown when modulated at 0.4 Hz. The LED lamp shows a better signal form, even at low frequencies. The shape of the emission and the impact of additional optics are characterised via the radiant intensity distribution curve. Finally, application examples of lock-in measurements using the LED lamp are presented.

References

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