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Optical Lock-in Thermography for Structural Health Monitoring – A Study into Infrared Detector Performance

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Abstract

This paper reports on a study comparing the noise performance of two relatively low-cost microbolometers to a high-grade photon detector as applied to optical lock-in thermography, a well-established broad area non-destructive inspection technique. The photon detector is shown to significantly outperform both microbolometers by margins inconsistent with their noise equivalent temperature detectivity specifications. It is demonstrated that this performance gap can be overcome by increasing observation time or optical illumination intensity. For practical situations in which such steps are plausible microbolometers may provide a viable alternative to photon detectors for optical lock-in thermography. This raises the prospect of applying this method to structural health monitoring, where the generally small size and low capital cost of microbolometers would be advantageous.

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Keywords: lock-in thermography; infrared thermography; non destructive inspection

1. Introduction

Maximising fuel efficiency and performance are major drivers for the growing use of lightweight, high-strength composite materials in aircraft construction. The prospect of lower through-life support costs is another advantage. Compared to their traditional metallic counterparts, composite structures are less prone to fatigue and corrosion which can impose significant maintenance costs as structures age. Where metals are demonstrably superior though is in impact resistance. Even relatively low velocity impacts to a composite can lead to significant structural damage,

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of which a particularly insidious form is barely visible impact damage (BVID) [1]. As the probability of such impacts occurring in the service life of an aircraft is relatively high (e.g. hail, debris, tool drop) the development of non-destructive inspection (NDI) techniques capable of rapidly and cost-efficiently finding such defects is an important priority for aircraft operators.

Active infrared thermography is a rapid, broad area non-contact NDI technique. It works by applying an optical or mechanical excitation (as either a pulse or modulation) to the specimen, and observing thermal contrasts generated by internal defects. Compared with more traditional NDI techniques such as tap testing and ultrasonics, active thermography is generally more rapid and cost efficient and is therefore viewed as an attractive first-line diagnostic inspection method [2].

The two most commonly applied active thermographic techniques are flash thermography (FT) and optical lock-in thermography (OLT). Both involve the application of an optical stimulation to a component, however they differ in the way it is applied. In FT, the excitation is a short-duration high intensity light pulse. For low conductivity materials such as composites this elicits (approximately) a thermal impulse response and thus provides a generally rich source of information about sub-surface anomalies. Although an effective inspection method, it requires the use of discharge tubes and bulky high energy capacitors, which add to the capital cost of the method and can detract from its portability. In OLT, the optical excitation is a persistent low-intensity modulation normally applied using an incandescent source. Such sources are significantly cheaper and generally more compact than a capacitor/discharge tube arrangement. A diagnostic evaluation is made on the basis of either the amplitude or phase of the measured response, which is typically obtained from a cross-correlation of the infrared video and the modulation signal. The correlation period is variable and is normally set on a case by case basis. Generally, a longer correlation results in a higher quality signal. This property provides, at least in principal, an opportunity to affect improvements in the practicality and affordability of active thermographic inspection.

A review of the research literature reveals an almost universal preference for the use of photon detectors for OLT applications. This is not surprising as this type of infrared detector offers a significant sensitivity advantage over the only other practical alternative; the thermal detector. The difference is approximately a factor of 2-3 in terms of noise equivalent temperature detectivity (NETD). For this reason, thermal detectors are only considered viable when temperature sensitivity is not paramount [3]. However, recently published findings [4] indicate that microbolometers may be capable of better performance than what the relative NETD specifications imply. In [4] performance comparisons were made between a photon detector and five different microbolometers. The microbolometers were found to exhibit better ultimate stress-sensitivity levels. While this seems counterintuitive it is plausible. For methods that employ synchronous averaging, such as thermoelastic stress analysis (TSA) and OLT, it is not the NETD that determines ultimate sensitivity but rather the fixed pattern noise floor, which is seldom specified by detector manufacturers.

This raises an obvious question. Do these findings also apply to OLT, or in other words, given a longer observation time can a microbolometer outperform a photon detector in a typical OLT application? An affirmative answer would have potentially significant implications, not the least of which is allowing a generally expensive and bulky instrument to be replaced with a much cheaper, smaller and more durable, reliable and energy efficient device. One area where this could prove beneficial is in full-scale fatigue testing of composite aircraft components. Such tests normally include planned stoppages to allow for NDI of the component, a practice that delays the testing and imposes considerable costs. A persistent monitoring capability would eliminate the need for such disruption and would provide a virtual real-time flow of information about the development and growth of damage thus facilitating a more responsive approach to test management.

The present paper reports on a study that examines issues central to the previous question. The performance of two different microbolometers is assessed against a high-grade modern photon detector in a series of controlled through-transmission OLT experiments on a metallic plate. Insights from these experiments are then used in assessing the results of single sided inspections of composite laminates containing varying levels of impact damage.