Optimising Probing Depth in Pulse Thermography Inspections of Composite Materials

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Abstract

Probing depth is a known limitation of active thermographic techniques applied to composite materials. The work presented aims to address this using data processing techniques on pulse thermography (PT) thermal data. A procedure is presented which is shown to improve probing depth by first compensating for experimental error inherent in the aquired raw thermal data. Then using pulse phase thermography (PPT) spectral leakage in the frequency domain is mitigated using hamming and flattop windowing functions in place of the traditionally used rectangular function. The use of these alternative window functions is shown to improve phase contrast and defect characterisation. It is also shown black paint typically applied to specimens to increase surface emissivity, can reduce thermal contrast and limit probing depth.

Introduction

Delamination of layered fibre reinforced polymer composites can arise from in-service loading, significantly reducing the strength and stiffness of a component [1], and can lead to failure if undetected. To enable timely repair, non-destructive examination (NDE) is carried out to identify and characterise critical defects. Pulse Thermography (PT) uses an infrared detector to monitor the thermal decay from a heat pulse applied to a component. It is a well-established NDE inspection method for composite materials, which identifies defects by exploiting differences in thermal properties between undamaged regions and defective regions. PT has the ability to provide rapid, full field, non-contact inspections [2] in the service environment, benefiting from its robust and simple set-up. However, the thermal response from the component is affected by environmental conditions such as surface reflections and probe depth (i.e. the deepest defect that can be detected) is limited by the low thermal diffusivity of polymeric resin systems. Pulse Phase Thermography (PPT) is a post processing technique that uses a Discrete Fourier Transform (DFT) to obtain frequency domain phase data from temporal PT data [3]. It is less sensitive to surface features and non-uniform heating, which improves probing depth.

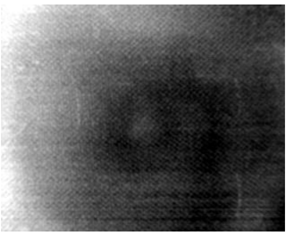
In the present paper it is demonstrates that the probe depth can be significantly improved by incorporating advanced signal processing methodologies that have not previously been applied to thermographic or other full-field imaging techniques. Conventionally [4], rectangular windows are applied to the temporal thermal signal measured at each pixel. The windowed signal is converted to the frequency domain using a DFT, and the result is used to calculate phase. Rectangular windows are considered to provide the best frequency resolution [5], however, unless specific sampling conditions are met, which cannot be achieved in PT inspections, rectangular windows cause spectral leakage [5]. The spectral leakage means that the energy for one frequency leaks into all frequencies over the sampling range. Since phase is frequency dependent, spectral leakage can mask the changes in phase that enable the identification of defects. Here a new approach for processing thermographic images is adopted that reduces spectral leakage based on using a windowing function that applies a weighting in the time domain. It should be noted that windowing has been used by others to extract spectral information from discrete signals [5]. It is shown that by using different windowing approaches identification of simulated defects is improved. In addition, it is shown that image processing in the time domain can be used to reduce the effect of the environment on the thermal data and provide improvements in defect identification without the additional PPT processing. Surface preparation prior to inspections is also considered for the purposes of improving defect identification. It is shown that traditional coatings applied to specimens prior to testing can negatively affect probing depth.

Materials and Experimental Methodology

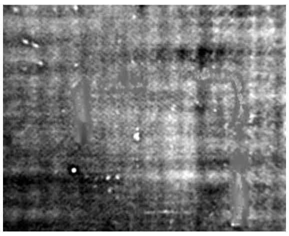
Resin infusion was used to manufacture a composite sandwich panel with glass fibre reinforced polymer face sheets and PVC foam core. The face sheets were manufactured using four plies of 540 gsm biaxial E-glass infused with Gurit Prime 20LV epoxy resin. Delamination defects were simulated using PTFE inserts placed between each ply of the GFRP face sheet laminate. Thermal data was acquired using pulse thermography in reflection mode. A FLIR SC5000 photon detector was used to measure the thermal decay of specimen surface. A Bowens Pro 1000 optical flash was used to provide thermal excitation. All data processing was carried out using algorithms developed on the Matlab R2016a platform. PPT was carried out using three windowing functions (rectangular, hamming and flattop) using raw thermal data and using thermal data processed to compensate for experimental error. Systematic errors such as non-uniform flash heating and vignette effects were compensated for and, random temporal noise was reduced using Thermal Signal Reconstruction (TSR) described in [6], applied pixel wise.

Results

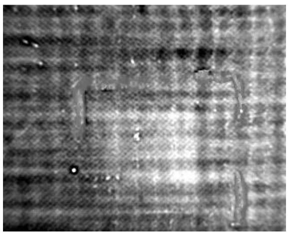
Simulated defects placed at 1.8 mm depth were not identified in the thermal data. Standard PPT procedure described in [4] was implemented, a typical phase image is presented in Figure 1 a). This was compared to an alternative processing routine, using alternative windowing functions. As shown in Figure 1b), hamming window performed well in comparison to rectangular window traditionally used.



a) Raw thermal data

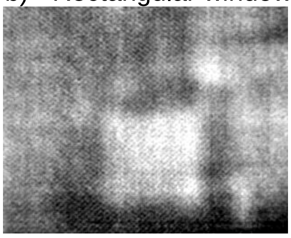


b) Rectangular window.

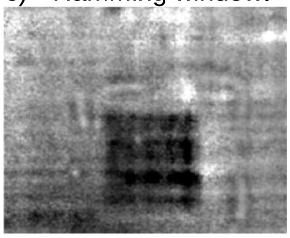


c) Hamming window.

d) Flattop window.



e) Corrected thermal data



f) PPT corrected thermal data

However, of the windows compared, flat top windowing function was shown to perform best. The flat top window improved probing depth of PPT, identifying simulated defects not found using rectangular window, and outperforming the hamming window. Processing time domain thermal data to compensate for experimental error was shown to significantly improve defect identification and characterisation in the frequency domain PPT phase results. It was also found that black painting specimens prior to inspection, reduced thermal contrast when compared to tests on uncoated specimens.

References

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