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Thermal differential sensing for defect inspection of carbon fiber reinforced polymer (CFRP) composite laminate

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Abstract

In this paper, a novel methodology, wave front-based thermal differential sensing is applied for defect inspection of carbon fiber reinforced polymer (CFRP) specimen. This technology samples the thermal radiation field emitted from the specimen and correlates thermal distribution spatially with time, and the reconstructed 3D thermal field profiles, where the thermal signature of the specimen is disclosed. The defect signals and inspection results are found more reliable and stable than traditional thermography.

1. Introduction

Traditional thermograph[1,2,3] acquires the absolute surface temperature distribution, and provides the intensity-based 2D image, which is momentous intensity distribution and sensitive to various noises, such as surface reflection, non-uniform heating and artifacts, and therefore thermography for defect inspection suffers relatively low reliability and sensitivity. In this paper, a wave front-based thermal differential sensing is applied for defect inspection of CFRP specimen.

2. Thermal differential sensing system

Thermal front based differential sensing is an exploratory integration of optical wavefront sensing [4,5] and active transient thermography. The active heating process is necessary to heat-up the specimen, and initiates thermal transfer inside the specimen and stimulates temperature difference. Thermal radiation waves are generated by the specimen, and propagate into the free space away from the specimen surface, and reveal the details of the thermal transfer inside the specimen. In this paper, thermal differential sensing system samples the thermal radiation emitting from the specimen and correlates it with a reference image of specimen itself close to thermal equilibrium. So it senses and describes the dynamic development of the thermal radiation field contributed from the whole specimen (not only the surface), and it can indicate the internal thermal signature and hidden defects beneath the composite outer surface.

The sensing system is built up as shown in Fig.1. It consists of a number of key hardware components: heating lamp, thermal sampling aperture, infrared lens and infrared image sensor-thermal detector, and image processing software for thermal field reconstruction.

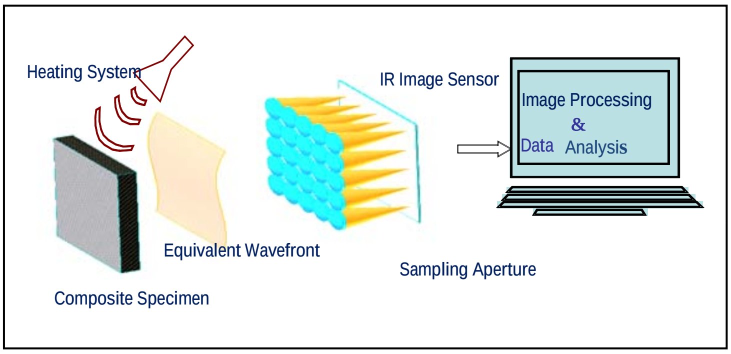


Fig. 1 *Sketch of thermal differential sensing system*

After time-controlled heating, the broadband thermal radiation from the specimen is sampled by the array sampling aperture, which can be a lenslet-array, or in some other forms [6]. The focused infrared optical spot array image is detected by the thermal detector (middle IR or long IR), and sent to the diagnostic program (DP) for data processing and analysis. The DP will process the 2D data, and reconstruct the equivalent 3D thermal radiation field profile as shown in Fig. 2, where the main data processing functions and thermal signal flow is illustrated.

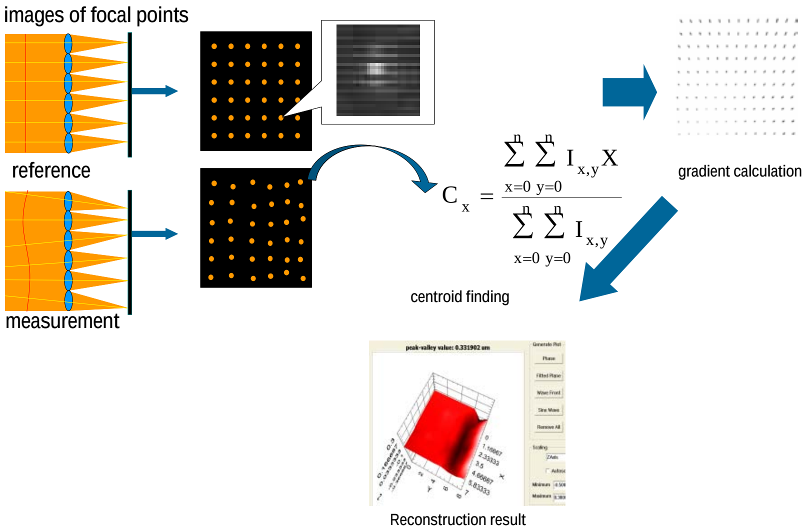
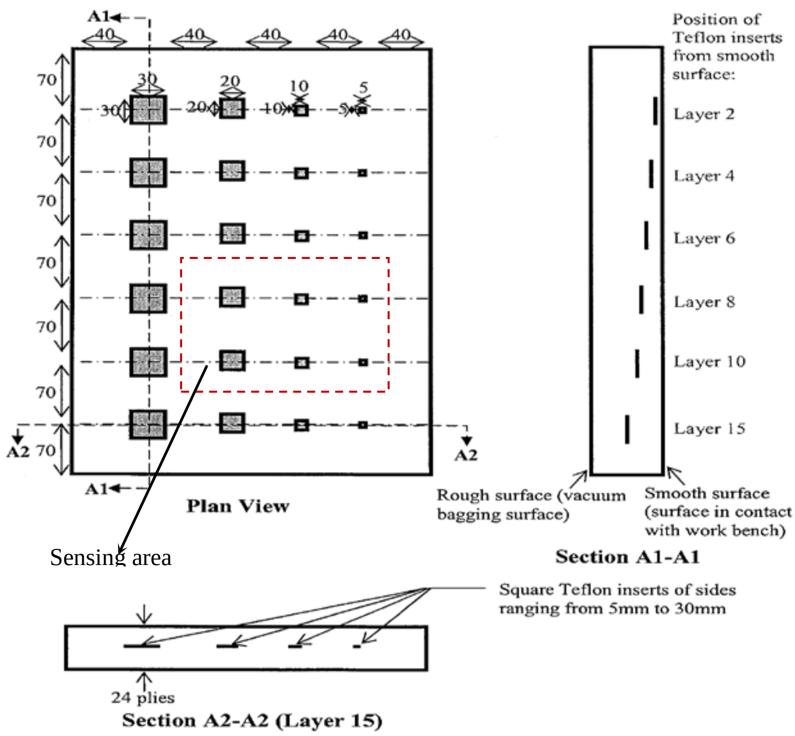


Fig. 2: The working principle of the diagnosis program--data processing and analysis

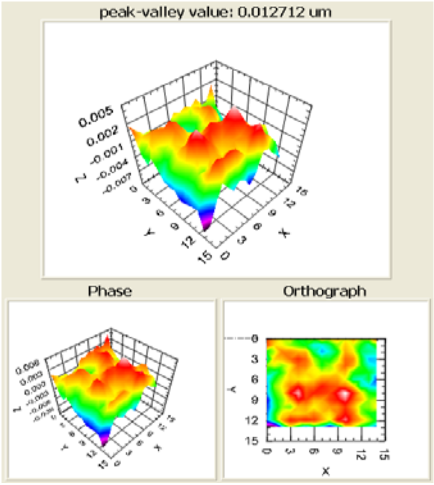
For the traditional wave front sensing technology, a good/non-defect sample with the same material and emissivity is needed to use as a reference for the defect inspection. Practically, this ideal reference is not available and other possible references must be created and investigated to replace the ideal reference. The reconstructed 3D radiation field profile will disclose the thermal signature and hidden defects in the specimen.

Thermal transfer and interaction, which exist in an active transient process anytime and everywhere in the specimen, is complicated and invisible. In our study, CFRP specimens are only heated up for less than 1 minute and thermal sensing is conducted in the normal air-conditioned open environment. Thermal radiation signal in the sampling plane is weak and is possibly mixed with various noises, such as reflections and unknown radiations from environment. Various factors are investigated to improve and optimize the system for defect inspection of different specimens with different thermal properties.

3. Experiments and results



(a)



(b)

Fig. 3 *Details of the structure (a) and inspection results (b) of the carbon fiber reinforced polymer (CFRP) specimen with built-in defects*

In the experiments, the defect inspection of a CFRP composite specimen is conducted in the following 3 steps: 1) The specimen is heated up to a certain temperature normally around 50 ºC -70 ºC. 2) The thermal radiation emitted from the heated specimen impinges onto the sampling aperture, is sampled, recorded and sent to the DP. 3) The DP processes the sampled data, reconstructs the thermal radiation field and extracts the thermal signature of the specimen and displays the inspection result.

Defect inspection of the CFRP laminate with built-in defects, as shown in Fig. 3(a), is conducted and the result as shown in Fig. 3(b) demonstrates that this methodology is feasible for defect inspection of CFRP composites. Certainly, it is just concept-proven, and is still open for further improvement for lowering down noise and redusing the system size.

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