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Impact Damages Detection on CFRP Using Eddy Current Pulsed Thermography

Abdoulaye Ba[a], Qiuji Yi[b], Junzhen Zhu[b], Huu-Kien Bui[a], Gui Yun Tian[b], Gérard Berthiau[a,1], Guillaume Wasselynck[a]

[a] *Institute of Research in Electrical Energy of Nantes-Atlantiques (IREENA), University of Nantes, 44602, Saint-Nazaire Cedex, France*
gerard.berthiau@univ-nantes.fr

[b] *School of Engineering, Newcastle University, Newcastle Upon Tyne, NE1 7RU, United Kingdom*
g.y.tian@newcastle.ac.uk

Abstract. Carbon Fiber Reinforced Polymer (CFRP) materials are widely used in aerospace due to their low weigh to strength ratio. Non-destructive Testing (NDT) Techniques becomes a necessity with increasing use of CFRP materials. Induction Thermography is a new NDT technique that can be exploited as a promising fast and global control. However, the detection of typical flaws in carbon composites such as delamination, fibers rupture and impact damages need to be further investigated in order to optimize the technique. Optimization can be done in the test configuration level and by the use an appropriate image technique. In this paper Eddy Current Pulse Compression Thermography (ECPuCT) is used to detect impact damages on CFRP materials. The Principal Component Analysis (PCA) based image processing technique is used to detect and visualize impact damage area from transient thermal images. Flaw detection results using experimental measures will be shown and discussed.

Keywords: Eddy Current Pulsed Thermography (ECPT), Eddy Current Pulse Compression Thermography (ECPuCT), Principal Component Analysis (PCA), Carbon Fiber Reinforced Polymer (CFRP), Non-destructive Testing (NDT).

1. Introduction

Eddy Current Pulsed Thermography (ECPT) [1] and Eddy Current Pulse-Compression Thermography (ECPuCT)[2] are one of the NDT techniques which can be applied for the non-destructive testing of various kind of conductor work piece such as Carbon Fiber Reinforced Polymers (CFRP). Induction Thermography system combines two techniques : Eddy Current and Thermography. The heat is not limited to the sample surface ; it can reach a certain depth according to the penetration depth of the electromagnetic wave into a conductive material. Eddy-Current Thermography focuses the heat on the defect area due to Eddy Current distorsion. This phenomenon increases

[1] Corresponding Author, Gérard Berthiau, Institute of Research in Electrical Energy of Nantes-Atlantiques (IREENA), University of Nantes, Nantes 44035, France; E-mail: gerard.berthiau@univ-nantes.fr.

the thermal contrast between the defective region and defect-free areas.

In this paper, experimental induction thermography testing will be carried out. The Principal Component Analysis is applied for ECPuCT thermal responses for quantitative analysis of a composite plate with impact damages of 9 J, 15 J, 16 J, 16.55 J, 18 J and 21 J. The composite Plate with impact damages was given to us by AIRBUS, as part of the PhD of Huu-Kien Bui [1]. The defects are evaluated by analyzing the heat distribution and patterns in thermal images. This paper will investigate whether impact damages can be detected using ECPuCT and Principal Component Analysis (PCA). Only the impact damage of 18 J will be investigated in this paper.

2. Principal Component Analysis (PCA)

The principal component analysis method is used to reduce data dimensions and extract main features. PCA is a multivariate statistical analysis method which transforms the ECPuCT thermal data into uncorrelated eigenvectors or principal components (PCs) corresponding to the maximum variability within the data. In PCA method, each principal component is a linear combination of the original variables. In general, the first principal components carry most of the information regarding the original data [3]. The detailed steps of Principal Component Analysis are summarized as follows :

- Organization of the dataset;
- Calculation of the mean along each dimension;
- Calculation of the deviation;
- Determination of the covariance matrix;
- Calculation of the eigenvectors and eigenvalues of the covariance matrix;
- Sorting the eigenvectors and eigenvalues;
- Computation of the cumulative energy content for each eigenvector;
- Selection of the first PCs.

3. Application on composite sample

Experimental ECPuCT system in figure 2 is used to investigate impact damage in a CFRP sample. The sample is a 37 plies composite plate with six impact damage defects. The composite plate has dimensions of $300mm \times 300mm \times 37h_{ply}$ where h_{ply} is the thickness of a ply which is equal to $140\mu m$. The defects are numbered from A1 to A6 as shown in fig. 1. The table 1 gives the dimensions of the composite plate.

Table 1. Characteristic of the composite sample

Number of ply	37
Lay-up sequence	X/0/X_S
X = [0°/0°/135°/0°/45°/0°/45°/90°/135°/0°/135°/90°/45°/0°/45°/0°/135°/0°]	

X_S denotes the symmetric lay-up sequence of X with respect to 0° ply.

The fig.1 shows the configuration of the composite sample with six impact damages from A1 to A6. In this paper, only the impact damage A3 will be investigated.

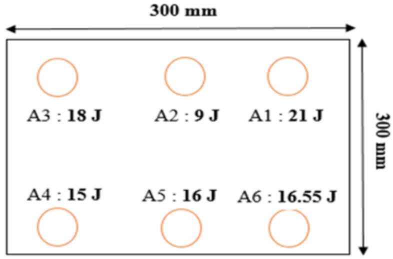

Figure 1. Composite sample with impact damages location.

The fig. 2 shows the schematic diagram of the used Eddy Current Pulsed Thermography for the experimental studies. The schematic diagram contains four units : a signal generator, an excitation module, an infrared camera and a computer.

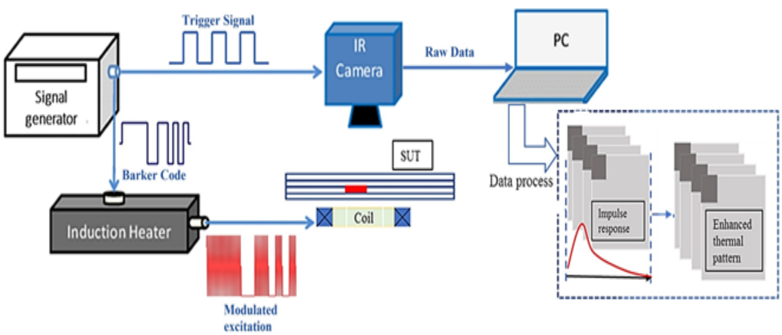

Figure 2. Eddy Current Pulsed Compression Thermography configuration[2].

A high frequency and high power signal generator provides high power currents for induction heating. Signal generator is used to send both the Barker code signal [2] to the induction heating coil and a reference clock trigger signal to the infrared camera to acquire thermograms at 50 frames per second. The induction heater is a Cheltenham EasyHeat 224 with a maximum excitation power of 2.40 kW, a current value of 400 A and an excitation frequency range of 150-400 kHz. An IR camera FLIR SC655 was used to record the thermal responses of the specimen. The camera has a resolution of 640×480 pixels at a frame rate of 50 Hz and a sensitivity of 7.5-14.0μm.

4. Results

In this section, we present the experimental results obtained in our work. After calculating the impulse response of the thermal images, PCA method is used to locate the impact area. Firstly, we plot the thermal response along the line A as shown in fig. 3. The line A crosses the area of the impact damage A3. We can expect that the thermal response on the area A3 be higher than surrounding area.

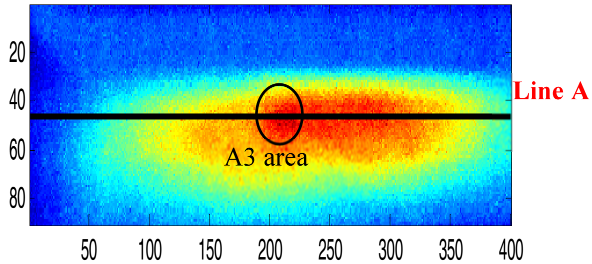

Figure 3. Thermal distribution along A3 at 1 s

Fig. 4.a shows the thermal response of two pixels. The curve of the pixel in blue is in the area of the impact A3 and for the red curve, the pixel is near to the impact area. We observe in the fig. 4.a three stages. The stage 1 and 2 are the heating stage but in the stage 2 we observe the effects of the Barker code which is a bit length of 13 with a series of 1 or -1. The temperature increases during this two stages. The last stage is the cooling stage. In this stage the temperature decreases gradually. The heating and cooling times are respectively 13 seconds and 30 seconds.

The fig. 4.b shows the thermal responses along the impact damage A3 at recorded time of 1 s, 2 s, 3 s and 4 s respectively. From the thermal responses of fig. 4.b, we can distinguish the area of the impact damage A3. Indeed, the thermal response in the area of the impact damage increases due to fiber breakage in the area of the impact damage. This can be observed by thermal lobes in fig. 4.b.

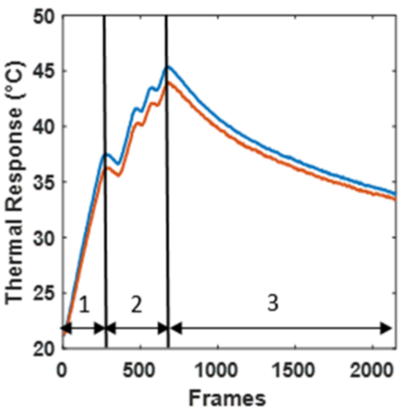

Figure 4.a. Thermal of two pixels

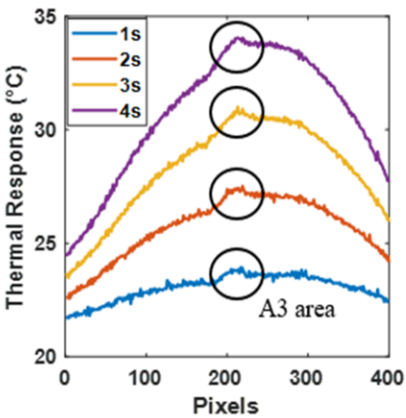

Figure 4.b. Thermal response along A3

From fig. 5, we can see that by using PCA method, the impact damage A3 is clearly revealed in the image reconstructed by the second principal component. The impact point is like a hot spot because the electrical conductivity is decreased at the impact point, which leads to Eddy Current diversion in the area of A3, increasing the Eddy Current density. The temperature at the impact point is higher than surrounding area. The effect of non-uniform heating is almost eliminated and only the area of the impact damage A3 remains in the second principal component image. The profile of the impact A3 can be precisely obtained using the PCA method. Above the 3rd principal component, the information useful for detecting the impact damage A3 is limited. To sum up, PCA is effective to enhance the features of impact damage in the IR image sequences by eliminating the effects of non-uniform heating.

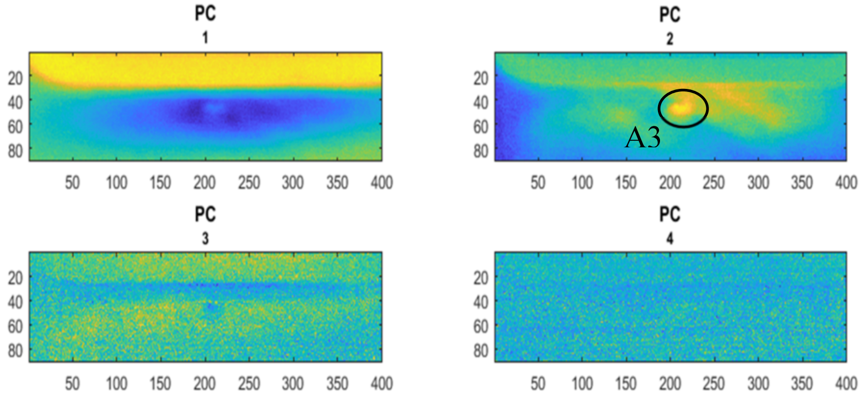

Figure 5. Results of ECPuCT testing. Images reconstructed by the PC 1, 2, 3 and 4

5. Conclusion

The experimental measurements have been conducted to investigate the performances of Eddy Current Pulse Compression Thermography (ECPuCT) applied to the detection of impact damage defects on a CFRP material. The principal component analysis has been applied to the ECPuCT data to identify impact area on the composite plate. The results show that the PCA can be used to eliminate the effect of non-uniform heating and reveal clearly the defect in the image reconstructed by the second principal component

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