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APLICATIONS OF TRANSIENT THERMOGRAPHY USING IR-NDT SOFTWARE

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Abstract : *This paper describes a set of applications resolved with IR-NDT software for inspection with transient (long pulse) thermography of CFRP (carbon fiber reinforced plastics) plate with known defects. The shape of the transient temperature descent curve is linked with defect parameters such as depth and size and was analyzed using specific software IR-NDT.*
Key words: *CFRP, pulse thermography, IR-NDT software.*

1. INTRODUCTION

Infrared thermography is a non-destructive evaluation method, consisting in infrared measurement and investigation techniques that are used in the inspection of subsurface defects and features, coating thickness, hidden structural irregularities or thermophysical properties.
The principle of infrared thermography consists in infrared radiation detection and recording of thermal anomalies of heat flow, thus producing a corresponding visual image, which is called thermogram [1].
Initially, inspection with infrared thermography has been used in military and medical domains. Later on, the technique becaming more advanced, it finds interesting applications as a nondestructive detection technique in engineering.
The domain of infrared thermography is quite recent and covers vast fields of applications. In the industrial context, infrared thermography is deployed either by the passive approach (by simple observation of the isotherms on the observed surface) or by the active approach (by stimulating the thermal response of the specimen).
Transient (long pulse) thermography consists in creating thermal waves on the surface of specimens, tested in transient regime.
In the experiment described in this paper, a comparison is made between thermograms obtained with transient method. The sample is a CFRP plate that contains nine flat-bottom circular holes of different diameters at the same depth.

2. GENERAL INFORMATIONS

Infrared thermography is a modern technique that allows obtaining two - dimensionsinal images, which are heat maps of the object inspected and they are easy to interpret.
In transient technique, also known as long pulse thermography, the surface under investigation is pulse heated (time period of heating being of few seconds, in contrast with that of milliseconds, used for short pulse or flash thermography) by one or more powerful lamps and the resulting thermal transient field at the surface is monitored using an infrared (IR) camera. The duration of the heating pulse depends on the thermal and physical properties of the materials, as well as its thickness. So, the heat flow into the sample is altered in the presence of a subsurface defect or feature, creating temperature contrast at the surface which can be detected in a thermogram obtained with the IR camera. In short, in transient thermography defects are detected because they affect the transmission of heat to the surface of the component [2].
The method is well suited for detecting the following defect types: delaminations, adhesive disbonds, impact damage, density of porosity, voids, inclusions, foreign objects (provided not thermally matched with the bulk material), water ingress, liquid contamination, corrosion, erosion and localized change in wall thickness, debonding between composite sandwich parts and liquid contamination of the core.

The basic setup of transient thermography is presented in figure 1.

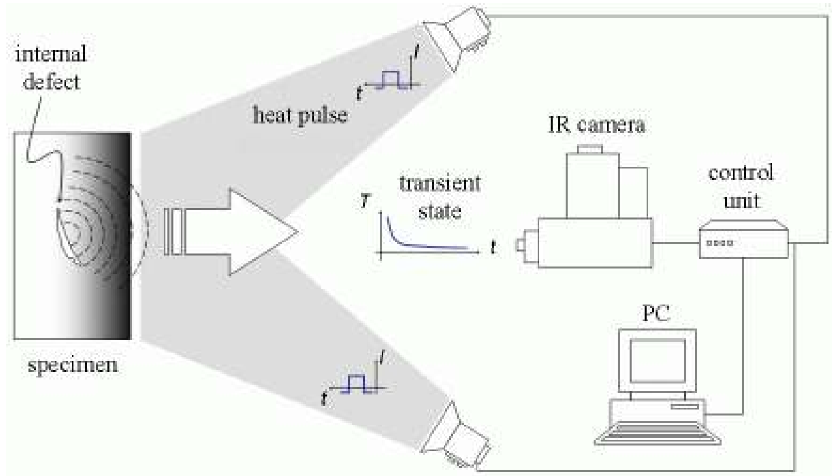

Figure 1: The setup of transient (long pulse) thermography.

The shape of transient temperature descent curve is represented by a sum of sinusoid functions that are individually mixed and reflects defect parameters such as depth and size [2]. The shape of transient temperature is analyzed by the Fourier series and is presented in figure 2.

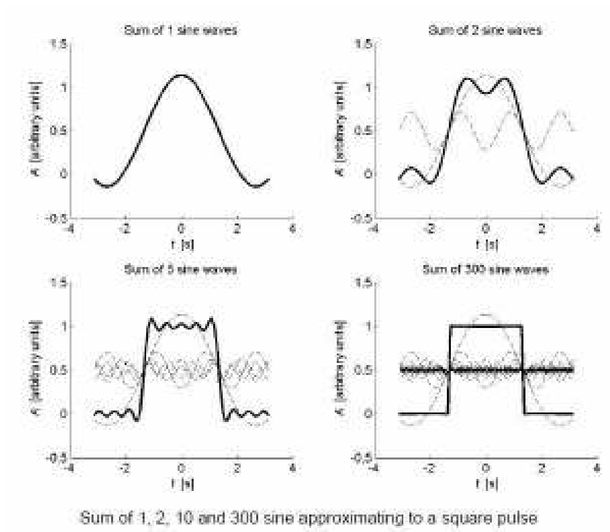

Figure 2: Shape of the heat flux/signal.

IR-NDT software is designed to carry out all tests in thermography nondestructive testing activities, regardless of method used and the excitation source, for any kind of material. IR-NDT software controls the hardware and provides acquisition of the thermographic images in real time. Through a series of high performance algorithms, the program evaluates each thermal image and highlights the structural flaws within the material [3].
The usage of all known emitters is possible and can be easily arranged. The display of temperatures and their variation in time for any number of areas of interest offers a very flexible opportunity range of usage for non-destructive material testing with active thermography.
Some of the main features of IR-NDT software are: functions for loading and storing sequences of images and static images, showcase for an unlimited number of areas of interest, flexibility in adjusting all parameters according to the IR camera connected to the system and the source of excitation, a wide range of algorithms for analysis in each test method used, calculation of a series of attributes for evaluation: phase, amplitude, n-derivative, display a series of simultaneous results, advanced techniques for analyzing images, thermographic measurement functions for fully automatic inspection - the system allows remote control and exports data to MATLAB or Excel [3].

IR-NDT interface is shown in figure 3:

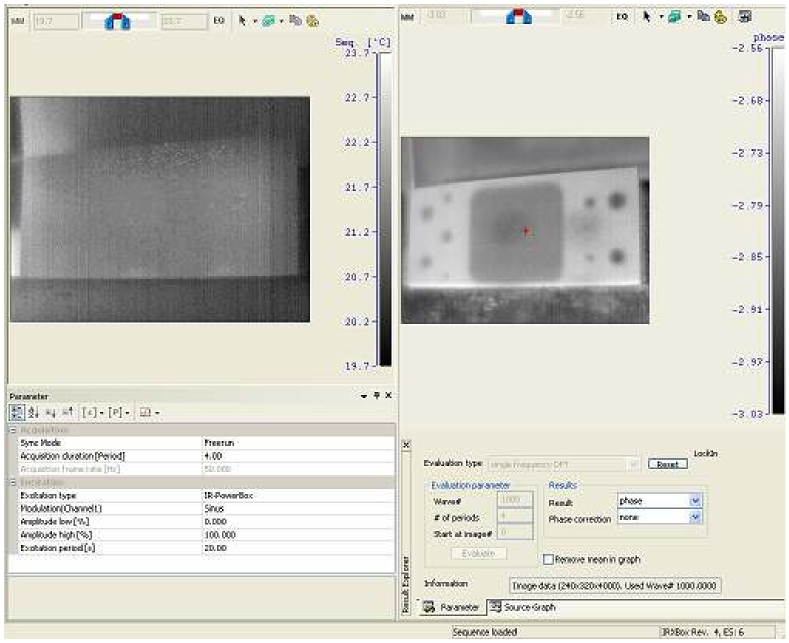

Figure 3: IR-NDT interface.

IR-NDT software is ideal for using in many applications concerning nondestructive testing, both for composite and metal structures. IR-NDT system modularity allows a high degree of flexibility in most cases requiring only the change of the excitation source. Integrating the whole system on a production line or using it in applications that require mobility is very simple. The control equipment is using standard interfaces, communication and data transfer devices to allow a rapid interpretation of results.

3. EXPERIMENTAL PROCEDURE

The integrated system aimed to perform transient thermography contains an excitation source (power electronics module and a panel with 4 halogen lamps). The power electronics module forms a functional unit with the IR-NDT software and IRX-box to control a connected lamp panel (actual power 2.6 kW). The IR-NDT package is an advanced software containing various functions for easy, versatile use. The non-linear electrical signal for the modulation of the heat source is generated by IRX-Box of the system. The modulation signal controls the power electronics and thus the power output of the heat source. The Flir A 40 M camera uses an un-cooled micro-bolometer detector with a frame rate of maximum 50 Hz and a focal plane array (FPA) pixel format of 320(H) × 240(V). This camera works in the spectral range 7.5-13 μm and has a thermal resolution 0,08ºC [4].
The calibration test specimen is a CFRP plate that contains nine flat-bottom circular holes of different diameters at the same depth, shown in figure 4.

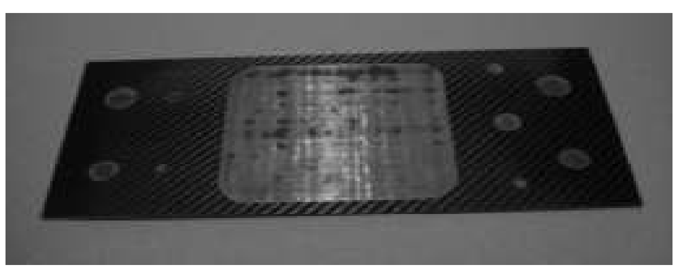

Figure 4: The CFRP calibration test specimen**.**

The thermophysical properties of material which is made the sample, are presented in table 1:

Table 1: The thermophysical properties of CFRP [5]

Material	$k[W/mK]$	$\rho[kg/m^3]$	$c[J/kgK]$	$\alpha[m^2/s]\times10^{-7}$	$e[Ws^{1/2}/m^2K]$
CFRP	7	1600	1200	36.5	3666

The experimental setup is shown in figure 5.

Figure 5: The experimental setup for inspecting the CFRP sample.

A temperature-time plot for a pixel marked with a red cross in the result image is shown in figure 6.

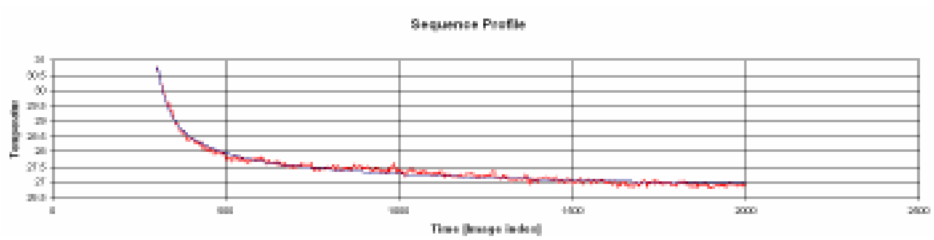

Figure 6: Heatig process in the target point.

The test parameters used during the experiments were: the excitation period – 40 [s], duty cycle - 15 [%], amplitude low – 0 [%], amplitude high – 100 [%], acquisition duration 40 [s]. The camera frequency image acquisition is 50 Hz, with that frequency getting 2000 images.
Experimental parameters have been chosen according to the material the inspected object was made of. With these parameters quite satisfactory results have been obtained.

4. EXPERIMENTAL RESULTS

The thermograms obtained with the pulse method, in different representations, are presented in figures 7-10.
The results obtained with this method are based on the reconstruction of infrared images calculated with a polynomial function that approximates the thermal behaviour in each point.
Residual representation consists in derivation of the recorded images and images reconstructed on this basis.

Figure 7: Thermogram obtained with residual representation.

Figure 8: Thermogram obtained with first derivative representation.

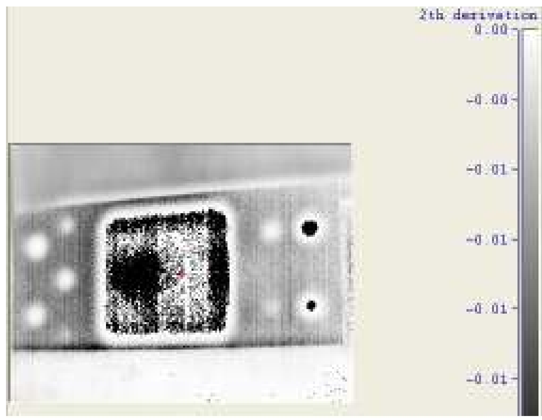

Figure 9: Thermogram obtained with second derivative representation.

The first derivation representation is the changing of the pixels along time axis. The same representation is made with the second derivatives.

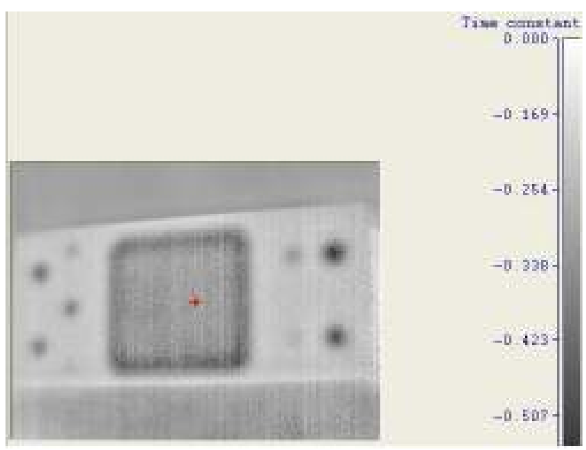

Figure 10: Thermogram obtained with time constant representation.

The results presented above were obtained with infrared thermography, the transient method, in a short time and some thermograms were influenced by uneven heating.
IR-NDT thermography program evaluates the CFRP sample inspected considering several configurations, like first and second derivative, residual and time constant configurations.
By studying the thermograms, a specialist can better understand the test system and can provide solutions to solve existing problems.

3. CONCLUSIONS

Transient (long pulse) method is suitable as a non-destructive inspection method for composite materials.
The thermogram obtained with the first derivative of the temperature field is more accurate and the defects are more visible.
For this experiment the reflection method was used, with the thermal source and the IR camera located on the same side of the object and in this case the appearance of damaged zone is a hot spot. One must be careful to avoid misinterpretation of the false irregularities which can appear on areas where the hotspot is a result of a direct reflection of the lamp (lamps).
Transient thermography is a fast NDI method when performed with modern integrated systems. For typical composite parts, the actual inspection takes less than 5 seconds without any surface preparation because a single experience launches a series of thermal waves at several frequencies in less than a minute. For conventional pulsed thermography the heating is the most time consuming process.
Because the heating period is small, this method is affected by non-uniform heating along the surface and this leads to the detection of only the near subsurface defects.
The research team is currently involved in the use of short pulsed thermograhy which is adequate for the inspection of metallic or FML materials, as the very short pulse heating is adequate for materials with high thermal conductivity.

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