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Conference Paper

Automation of Analysis of Thermographic Images in Diagnostics of Honeycomb Core Structure States

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Abstract

A method for converting the results of an active thermal imaging control of products made of polymer composite materials, using the Theil-Sen estimator, is described. Approbation of the described translation algorithm operation on a sample made in accordance with the technology of manufacturing the aircraft plane part is carried out.

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1. Introduction

Composite materials find expanding applications in a modern aircraft industry. In addition to high strength characteristics, the parts made of composite materials have a much greater mass efficiency when compared to metal parts. The use of such parts not only ensures the reliability of aircraft plane units throughout its life cycle, but also allows to use fuel most economically.

Compositional materials are those possessing the following set of characteristics:

- do not occur naturally, because they are man-made;

- consist of two or more components differing in chemical composition and separated by a defined boundary;

- have properties different from the properties of their components;

- are non homogeneous at the microscale and homogeneous at the macroscale;

- composition, form and distribution of components are "designed" in advance;

- properties are determined by each of the components that thereby should be present in the material in a sufficiently large amount (more than a certain practical composition). One of the components of the composite material is continuous throughout the volume and is called a matrix, a discontinuous component

separated in the volume of the composition is considered to be a reinforcing or armoring component [1].

Currently, an active thermal imaging technique is widely used for production and operational control of aircraft plane parts and units made of polymer composite materials. The technique can be used as a primary one and as an additional one, for example, to redetermine the boundaries of defects.

The active thermal imaging technique refers to the most reliable and least time consuming techniques for monitoring and diagnosing three-layer composite structures with a honeycomb core. In comparison with the X-ray technique, the thermal imaging technique is safe for the operator and allows you to get the result in less time.

To implement the technique in the field, for example, when controlling aircraft during operation, it is sufficient to have a thermal imaging camera and a heating source (metal halide lamp, heat gun, inductance coil, etc.).

The most important parameter in the active thermal imaging control of interlaminar separations and glueline defects is a temperature signal, i. e. the difference between the temperature of a defect area and a defect-free one. Computer processing is designed to enhance this difference on the already obtained thermal image, to simplify further decoding.

There are various approaches to processing the results of active thermal imaging control, for example, a dynamic thermal tomography technique described in [2] and a thermal imaging control with the use of a fast Fourier transform [3].

When working outside the laboratory, a transformation method is needed that allows you to quickly and with a minimal number of small adjustments convert the results of control into a decoding-friendly form.

The purpose of this work is to automate the analysis of the results of an active thermal imaging control when diagnosing three-layer honeycomb structures.

2. Materials and techniques

An array of thermograms for subsequent processing was obtained on an installation consisting of a thermal imaging camera, an infrared heater and an electric pulse generator. The control was carried out as per one-sided scheme, that is, the heating source and the thermal imaging camera were located on one side of the object under control. Such a control scheme is most often used for field control, since access from both sides to the object under control during its operation is not always possible.
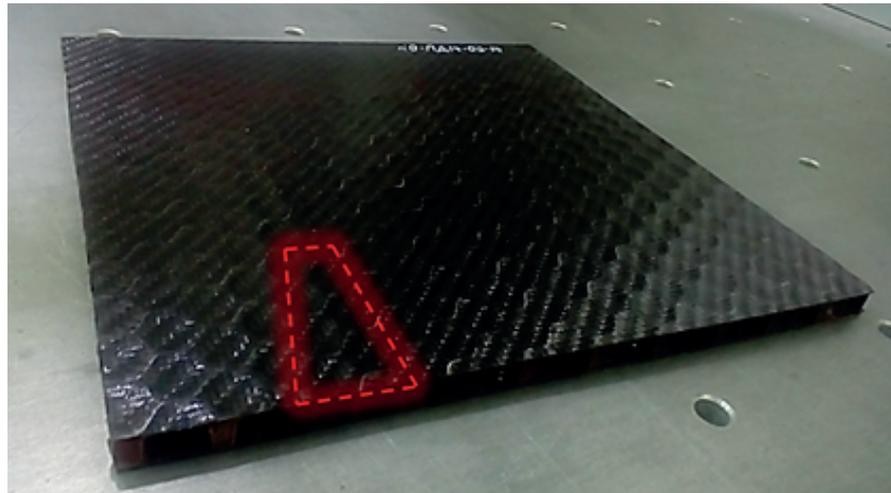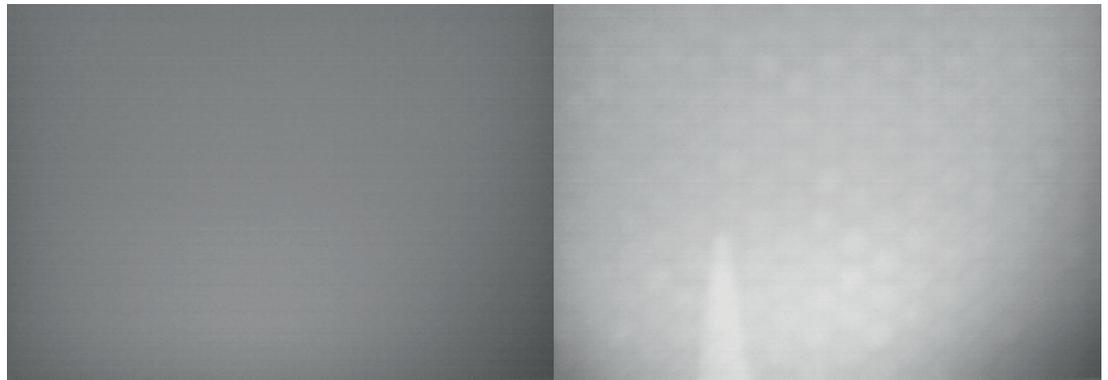
Figure 1: Control sample.

Figure 2: Thermograms of the sample at the beginning and at the end of sample heating.

As a control object, a three-layer sample with carbon fiber-reinforced plastic coverings with polymer honeycomb core was used (Fig. 1). An artificial imitation of the interlaminar separation of the covering was performed by laying a metal foil between the layers of prepreg before moulding, followed by the extraction of foil from the moulded covering.

The thickness of the coverings of this sample is 0.8 mm, the size of the cell wall is 10 mm. With such parameters of the control object, a non-destructive testing when impedance technique or free oscillation technique is used, is rather difficult.

In the course of active thermal imaging control, an array of thermograms was obtained at this installation. Resolution of thermograms: 408 x 240. The number of thermograms in the array is 122. An example of thermograms at the beginning of the measurement and when the sample with an artificial defect simulator is heated, is shown in Fig. 2.
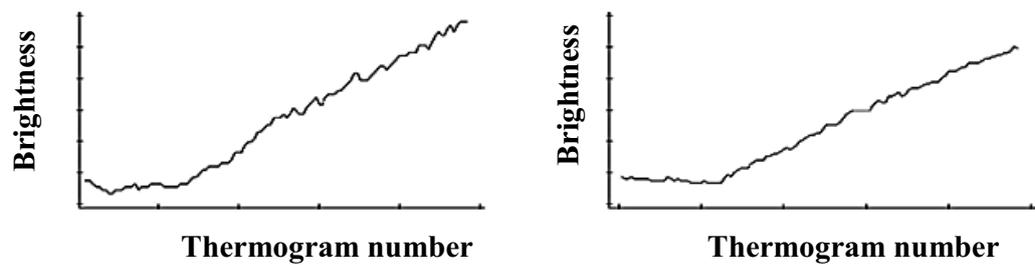
Figure 3: Change of the brightness of two pixels selected in the defective (left) and defect-free (right) areas.

3. Results

The developed technique assumes transformation of an array of thermal images into two-dimensional numerical arrays, which elements are the brightness values of each of the image pixels. The dimensionality of numeric arrays is equal to the resolution of thermograms.

At the first stage of processing, each of the matrices is decomposed into 3 submatrices according to the colour decomposition, into channels: red, green, blue. At this stage, you can also replace hot pixels, that is, those elements of the thermal imaging camera matrix which output signal value has a functional connection with the input signal, with the average value of adjacent pixels. Criterion for determining hot pixels: for defect-free pixels, the following equality is correct:

$$Y_r = Y_g = Y_b,$$

where Y_r- pixel brightness in a red channel,

Y_g- pixel brightness in a green channel,

Y_b- pixel brightness in a blue channel.

The replacement formula for defective pixels is as follows

$$Y_{ij} = \left(Y_{i+1j} + Y_{ij+1} + Y_{ij-1} + Y_{i-1j}\right) \div 4,$$

where Y_{ij} – brightness value for a point with the coordinates i and j.

Fig. 3 shows the relation between the brightness of two pixels selected in the defective and defect-free areas and the sample heating time.

The slope of the straight line after the inflection point is determined by the heating rate of the corresponding portion of the sample. To estimate a slope angle we used a

robust technique based on calculating the median of all possible partial angles of the slope of the temperature growth graph line.

$$\frac{y_j - y_i}{x_j - x_i}, \text{ where } i < j$$

This technique is called a Theil-Sen estimator. This functional relation is completely insensitive to emissions and in some cases can be significantly more accurate than the non-robust least-squares technique. The Theil-Sen estimator can tolerate up to 29.3% distortion of input data without decreasing its own accuracy. [4]

The Theil-Sen estimator calculation was carried out as per Siegel technique [5]. First, for each sample point (x_i, y_i) we calculated the median m_i for slope coefficients $(y_j - y_i)/(x_j - x_i)$ of the straight lines passing through this point, and then we calculated a general estimate as a median of the values of the resulting one-dimensional array of medians.

Application of this analysis technique eliminates the need to determine the heating start point (inflection point in Figure 3), which further facilitates the procedure for analyzing the results of an active thermal imaging control. As a result of applying the algorithm, a matrix of heating rates (slope angles) was obtained.

4. Visualization of processing results

Data processing was carried out in the environment of the programming language Dyalog APL [6, 7] oriented to the processing of arrays as a whole. The main features of the APL language are the following:

- compaction – the recording of the algorithm (program) on APL takes more than 10 times less lines than in any other programming languages (C, Pascal, Basic, et.al)
- Single characters are used to write functions and operators. In addition, most symbols are used ambiguously – as a unary function and as a binary function, these functions possibly being quite different.
- orientation for working with arrays.
- maximum meaning of all functions and operators: all are available in a variety of functionality options, depending on the number and dimension of the arguments (one argument or two, scalars or arrays, etc.).
- orientation to solve the problem and to describe the algorithm, independence from the architecture of the computer and the operating system.

• interactivity: interpreted APL became one of the first interactive computing environments, this fact made a significant contribution to its success. [8].

The process of data conversion in the language APL is presented below.

Creating bitmap objects:

('b', ¨⌽ ¨ι ρ bmps){α ☐WC'bitmap'(path,ω)}¨bmps;

creating a variable with color matrices:

cb←{ω ☐wg 'CBits'}¨'b', ¨⌽ ¨ι ρ bmps;

the dimension of each of the first three color matrices:

ρ ¨3↑ cb

240 408 240 408 240 408;

decoding all the matrices in three colors channel and assigned them to a variable:

rgb←{(3/256)⊤ ω }¨cb;

averaging all matrices between their own and reassigned:

rgb←{(+⌿ω)-(⌈ ⌿ω)+⌊ ⌿ω }¨rgb;

creating a variable of median:

M← {med 0,(1↓ ω)-¯1↓ ω } ¨⊂ [1]G;

ноw many medians are zero and one:

+/0 1∘ ·=,M

63387 13413;

Creating a bitmap object medians and assign it to the form:

'BB'☐wc 'bitmap' ('bits' M)

f1·Picture←BB·

At the last stage, the obtained numerical matrix of heating rates (slope angles) is visualized. Its decoding is possible by traditional techniques, for example, using cluster analysis [9]. The visualization of this matrix with the use of different filters (the number of gradations in brightness) is of particular interest. For example, to obtain a thermogram in a binary form (Fig. 3 on the right), a median of the values of the partial slope angles was calculated, then the values exceeding the median value were taken as unity (white colour) and the values lower than the median – as zero (black colour). The results of this processing for the thresholds of 50 and 25% are shown in Fig. 4.

The defect and the temperature signal of the honeycomb core on a thermogram with a greater number of shades of grey are more clearly visible than on any of the thermograms of the array. An artificial thermogram in a binary form is the most suitable one for working in a fully automated operation mode of a non-destructive testing installation. It lays the basis for the further possible creation of an automatic defect
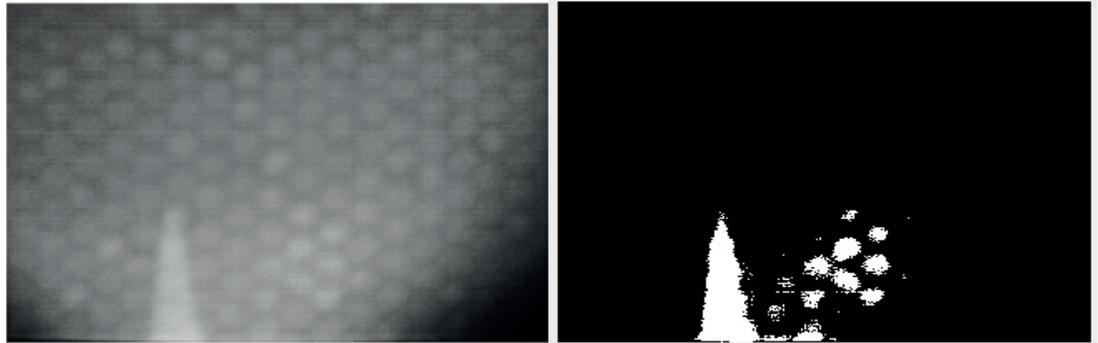
Figure 4: Visualization of heating rates at different filter levels.

detector (ADD) for automated non-destructive testing systems where the thermal imaging technique is used.

5. Argument

Obviously, the thermogram in a binary form has a disadvantage, because the area of a false defect is developed on it. This effect is caused by an unequal heating of the control object, because an infrared source with spherical lenses was used for heating. Improving the heater by installing an additional Fresnel lens should eliminate this negative effect.

However, this feature may be used to assess the equality of heating during an active thermal imaging control and when deciding whether the heating source is suitable for control.

6. Conclusion

The undertaken research resulted in developing a new approach to the analysis of the results of an active thermal imaging control, and that makes it possible to automate the process of decoding thermographic images.

The developed technique allows to effectively reduce noises in the thermograms, to eliminate the effect of glare from the surface created by static sources of heating, to determine the defect area with high accuracy, and it has less complexity than available analogue techniques. The operational efficiency of the technique is verified on a sample manufactured according to the technology of manufacturing a real aircraft. The reliability of the obtained results is proved. It is concluded that the developed technique can be used for the non-destructive testing by the active thermal imaging

technique in regard to the structures made of polymer composite materials with a honeycomb core.

References

[1] Composite materials: handbook. / V. V. Vasilyev, V. D. Protasov, V. V. Bolotin and others; under the general editorship of V. V. Vasilyev, Yu. M. Taranopolsky M.: Mashinostroenie, 1990 – 512 p.; illustr'd

[2] Works laboratory. Material diagnostics №3. 2006. Volume 72. V. P. Vavilov. Dynamic thermal tomography (review)

[3] O. N. Budadin and others. Thermal imaging control technique with the use of a fast Fourier transform.

[4] URL: http://www.imash.ru/netcat_files/File/lebedev/2007-a-Budadin-Fourier.pdf (reference date: 05.12.2017).

[5] Richard Fernandes, Sylvain G. Leblanc Parametric (modified least squares) and non-parametric (Theil–Sen) linear regressions for predicting biophysical parameters in the presence of measurement errors // Remote Sensing of Environment. — 2005. — Vol. 95, ed. 3. — P. 303–316.

[6] Andrew F. Siegel Robust regression using repeated medians // Biometrika. — 1982. — Vol. 69, ed. 1. — P. 242–244.

[7] Dyalog Language Reference Guide. URL: http://www.dyalog.com/documentation (reference date: 05.12.2017).

[8] Bernard Legrand. Mastering Dyalog APL: A Complete Introduction to Dyalog APL. Dyalog Limited. First edition - 2009.

[9] APL. URL:http://progopedia.ru/language/apl/ (reference date: 06.07.2016).

[10] Yanchang Zhao, Yonghua Cen. Data Mining Applications with R. Elsevier Academic Press-2014. P. - 471