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ARTICLE *in* RUSSIAN JOURNAL OF NONDESTRUCTIVE TESTING · AUGUST 2015

Impact Factor: 0.3 · DOI: 10.1134/S1061830915080033

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ISSN 1061-8309, Russian Journal of Nondestructive Testing, 2015, Vol. 51, No. 8, pp. 520–523. © Pleiades Publishing, Ltd., 2015.
Original Russian Text © A.O. Chulkov, L. Gaverina, C. Pradere, J.-C. Batsale, V.P. Vavilov, 2015, published in Defektoskopiya, 2015, Vol. 51, No. 8, pp. 72–76.

Water Detection in Honeycomb Composite Structures Using Terahertz Thermography

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Received February 6, 2015

Abstract—Experimental results on the detection of latent water in a honeycomb fiberglass structure using terahertz thermography are presented. These data are compared with data that were obtained using active infrared thermography.

Keywords: terahertz radiation, terahertz thermography, infrared thermography, honeycomb structure, water detection

DOI: 10.1134/S1061830915080033

INTRODUCTION

The skin of the fuselage, wings, elevation rudders, and other units of the majority of modern aircraft is made using honeycomb structures that are composed of two skins (base layers), which are connected by a honeycomb and bordered over their perimeter by frame units. Water accumulation in comb cells during the operation of an aircraft may result in the degradation and subsequent destruction of critical units. Both the passive and active methods of infrared (IR) thermography are known and are used by leading aircraft building firms for the detection of condensed moisture in honeycomb panels of aircraft and work via surface thermal anomalies, which arise during nonstationary heat exchange and are caused by the high heat capacity of water [1, 2].

The interest in the utilization of electromagnet radiation in the terahertz (TH) range is increasing due to the features of its interaction with matter. The structural inhomogeneities of materials are detected and visualized using pointwise scanning [3, 4]. Terahertz "vision" is possible using infrared imagers in combination with so-called thermal converters, which, for example, are made based on thin targets that absorb THz radiation ("carboxylic" paper) well [5, 6]. Such a technique is applied in the present investigation for the detection of water within fiberglass honeycomb panels.

THE EXPERIMENTAL DEVICE

The experimental device, which is represented in Fig. 1, includes a THz radiation source, which is based on a Gunn diode with a power of 40 mW (Virginia Diodes Company) with a fixed frequency of 110 GHz and a wavelength of 2.8 mm; a "slit" monitoring circuit is used. The THz beam was collimated by a system of high-density polyethylene lenses that provided a monitoring area of 1600 mm^2 at a distance of 350 mm (the distance from the THz source to the object was 250 mm). The modulation of the THz beam was carried out using a mechanical shutter (Uniblitz) with an operation period of 2 s. The visualization of the spatial distribution of the power of the THz radiation that traverses the object under investigation was achieved using a THz objective (ALPhANOV), which was mounted on the objective of a FLIR SC7000 IK infrared imager (an IR matrix with 256 × 320 elements, a spectral range of 7–14 μm) together with a T-thermal converter (NeTHIS).

THE INSPECTED OBJECT

As the inspected object, a fiberglass honeycomb structure (Fig. 2), which was transparent to THz radiation, was chosen; its dimensions were 170 × 180 × 25 mm; the thicknesses of the front and back skins were 2 and 3 mm, respectively, and the cell volume was 700 mm^3.

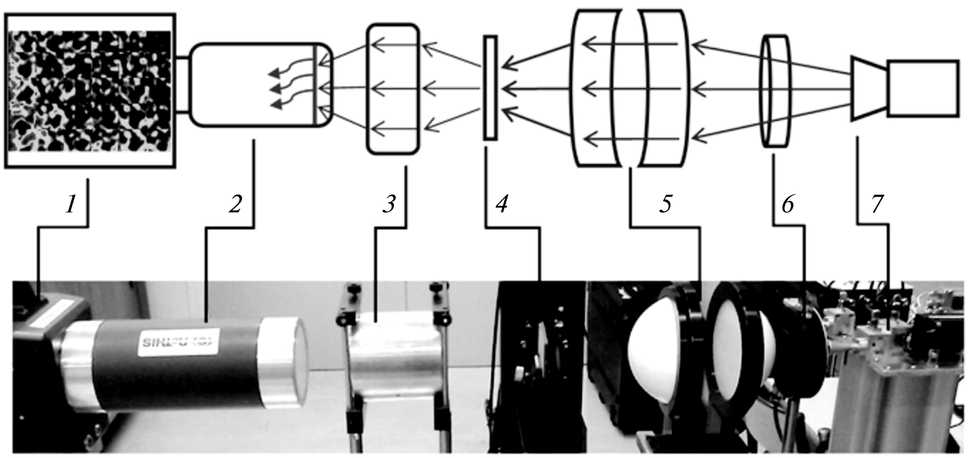

Fig. 1. The schematic of the experimental device: (*1*) IR camera; (*2*) tera-thermal converter; (*3*) terahertz objective; (*4*) inspection object; (*5*) lens system; (*6*) mechanical shutter; and (*7*) THz source.

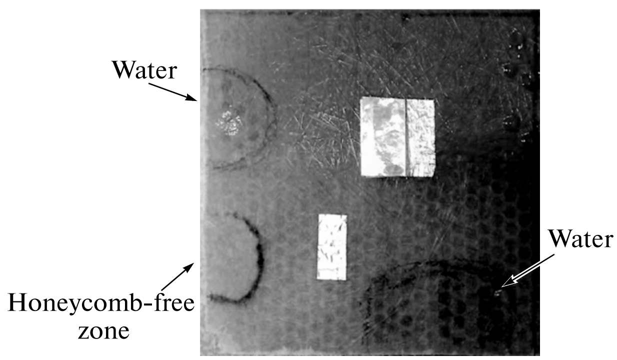

Fig. 2. A fiberglass honeycomb structure.

The cells of the honeycomb structure were filled with water using a syringe, which did not harm the panels, and introducing the syringe needle into the end parts of the article. The total area of two water-filled sections was 25.2 cm^2. To control the THz radiation transmission, 40 × 40 and 15 × 30 mm aluminum foil markers, which were not transparent for terahertz radiation, were arranged on the inspection object. In addition, the specimen had a technological section without honeycombs, in which the composite was thickened because of the "fusion" of adjacent cells. Thus, we used the facts that aluminum reflected THz radiation well, water absorbed it, and fiberglass is a semitransparent material.

RESULTS AND DISCUSSION

The object was arranged on a ZABER controlled motorized bench for scanning by two coordinates with a step of 40 mm. The article was inspected in every position for 2 s (the time of the transient process in the target of the tera-thermal converter) at a THz beam sectional area of 1600 mm^2 in the specimen plane. The total image of the article was "pasted" from 30 single thermograms using the method of the analysis of basic components [7]. Aluminum markers (Fig. 3a) reflected THz radiation and the latent water (Fig. 3b) absorbed it practically completely, whereas the composite itself revealed substantial transparency.

The diffuse boundaries of THz images of aluminum markers and the nonuniform pattern of defect-free sections are caused by the diffraction of millimeter THz waves. The visible contours of the technological section are caused by some absorption of THz radiation at cell interfaces because of the fusion of the component.

To identify water-filled cells and to compare them with "non-transparent" zones, where THz radiation damping at cell interfaces occurs, we analyzed four sequences of IR images, viz., a defect-free zone, a section with heightened density because of cell fusion, aluminum markers, and water-filled cells (zones *1*, *2*, *3*, and *4*, respectively, in Fig. 3).

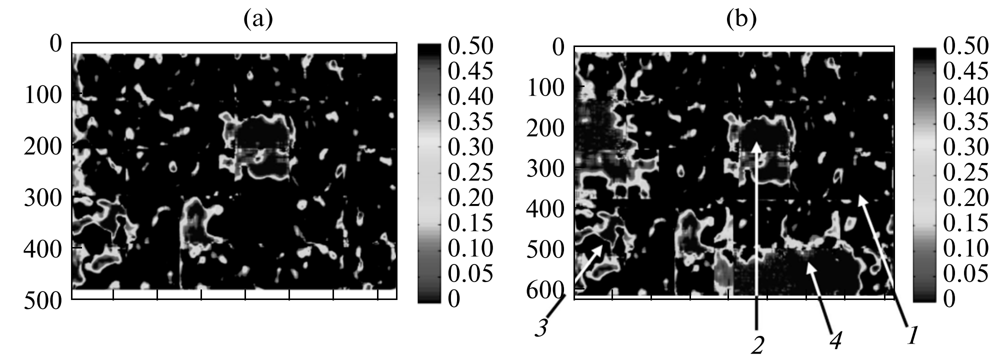

Fig. 3. A "pasted" THz image of the fiberglass honeycomb structure: (a) a water-free honeycomb structure; and (b) a water-filled honeycomb structure.

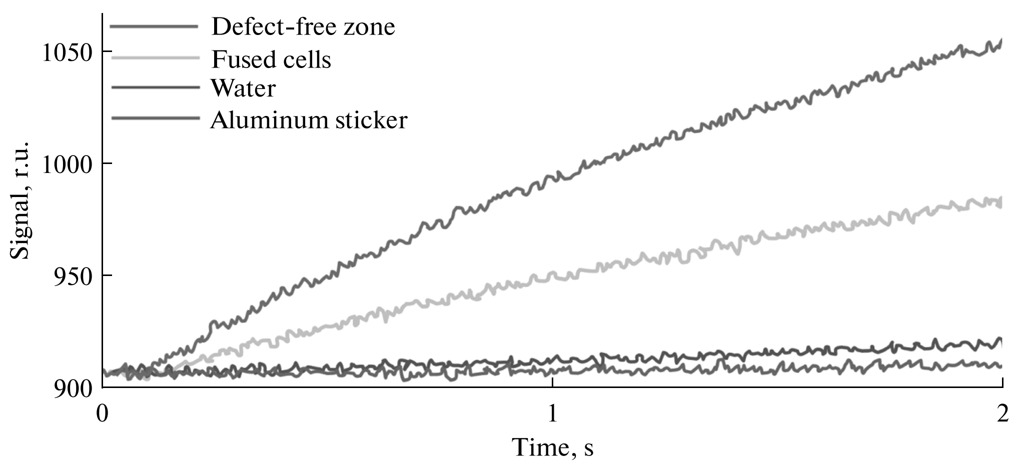

Fig. 4. The change in the THz signal in different areas of the inspection object.

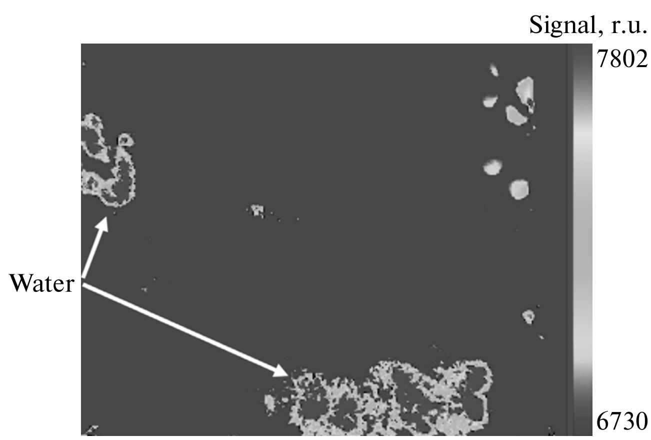

Fig. 5. An IR thermogram of the fiberglass panel with two sections of latent water (method of one-sided active IR thermography).

The change in THz signals in single sections of the inspected object is graphically represented in Fig. 4. The signal is absent in the marker zone and in sections with water, whereas it increases in transparent zones to saturation for several seconds of accumulation due to the heating of the target. Thus, water-containing honeycomb cells are effectively detected during signal accumulation for several seconds.

Comparison tests were carried out for the same specimen using the standard method of active IR thermography. Heating was performed using two xenon flashlamps with a total energy of 6 kJ. The image in Fig. 5, which presents a temperature conduction map that was obtained using the method of an asymptotic gradient [8], completely corresponded to the THz image; however, it was characterized by higher spatial resolution because of the use of a full-frame matrix IR detector.

CONCLUSIONS

Active IR thermography is an accepted method for water detection in the honeycomb panels of aircraft. The electromagnet radiation of the THz range, which is nonionizing and easily penetrates through composite carbon fiber-free materials, can be effectively used for the detection of latent water as well. The test performance, which attains about 1 m^2/h, makes it possible to achieve 100% inspection of objects with large areas; however, the necessity of double-sided access, the labor intensiveness of the adjustment of the scanning device, and the necessity for the observance of safety regulations make THz nondestructive inspection a laboratory rather than a practical method for testing that requires further investigation. Because the results that are described here were obtained using a device that includes both a tera-thermal converter and an infrared imager, further investigations are planned with the simultaneous determination of the IR and THz radiation characteristics, which can be used for the development of tomographic procedures.

ACKNOWLEDGMENTS

This work was supported by the Government order of the Ministry of Education and Science for 2014–2016 (project NIR no. 445(ONG)).

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Translated by S. Ordzhonikidze