Advanced ultrasonic testing of complex shaped composite structures

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Abstract. Due to the wide application of composite materials it is necessary to develop unconventional quality control techniques. One of the methods that can be used for this purpose is ultrasonic tomography. In this article an application of a robotic ultrasonic system is considered. Precise positioning of the robotic scanner and path generating are defined as ones of the most important aspects. This study proposes a non-contact calibration method of a robotic ultrasonic system. Path of the scanner requires a 3D model of controlled objects which are created in accordance with the proposed algorithm. The suggested techniques are based on implementation of structured light method.

1. Introduction

Nowadays advanced technologies require development of high-quality materials. Carbon fiber composites are widely used for construction of complex shaped objects. The wide range of its properties, such as high stiffness, low weight, high tensile strength and temperature tolerance, make them very useful for different areas, such as nuclear industry as well. For instance, carbon fiber reinforced silicon carbide (SiCf/SiC) was suggested for further development of the very high temperature reactor (VHTR) due to its ability to tolerate higher operating temperature [1].

However, this complex structure of materials causes the necessity of unconventional testing techniques. One of the most promising methods is ultrasonic tomography due to the ability of visualization of the results with quite high accuracy.

Testing procedure consists of several steps and each of them effects the accuracy of the final results. This study suggests an ultrasonic testing technique applying a robotic scanner. The major challenge in this case is making setting of the scanner. Therefore, the precision of positioning of the robotic scanner and generating the right path for the scanner is very important.

Positioning requires relevant correlation between coordinate system of the scanner and given points of the controlled object. A non-contact calibration method was proposed for this purpose. The scanning path can be generated in accordance to 3-D model of the surface of the controlled object. This paper suggests creating of the model by means of 3-D reconstruction techniques based on the structured light method.

2. General aspects of testing technique

Methods of positioning of the scanner and controlled object were studied for robotic ultrasound tomography system (see Fig.1). This system consists of ultrasound electronics unit, scanner and

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immersion tank. Ultrasound electronics unit itself contains the unit of control of the path and PC for displaying of the results.

Ultrasound electronics unit performs mainly the functions connected with transmitting and receiving acoustic signals, multiplexing of channels, digitizing of the signals, data transfer and processing. This unit has the following technical parameters:

- 128 multiplexed channels (16 parallel channels)
- capacity of 200 MB/s
- voltage of transmitting module: from -50 to -180 V
- the minimum of input sensitivity: 100 mkV
- the maximum of input voltage: 10 V
- the resolution of AD converter: 14 bit
- sampling frequency: 20 MHz
- AD buffer: 64 000 measurements.

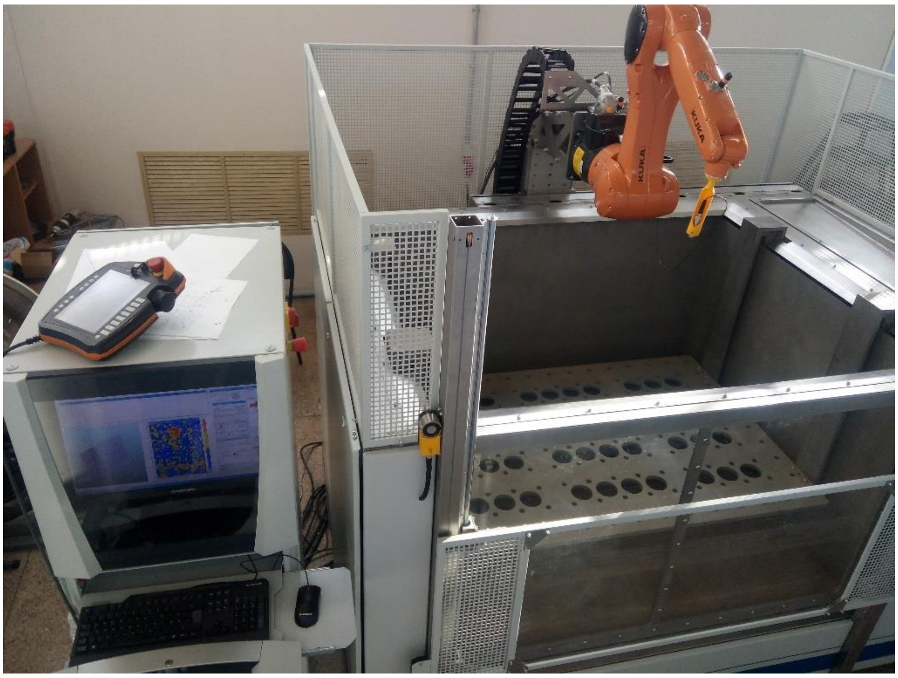

Figure 1. Robotic ultrasound tomography system

2.1. Non-contact calibration of a robotic scanner

As it was mentioned above, for accurate positioning it is important to estimate the relative position of the scanner and the controlled object. At present, contact calibration methods are applied for this purpose. These techniques imply that an operator determines each point of the object manually. Unfortunately, it can lead to huge uncertainties in the results and is very time-consuming.

That is why, we suggest to implement a noncontact calibration method. The proposed method applies 3D- scanner system that will make the process of determination of the coordinates automatic which means less time-consuming and more accurate.

Industrial robot is applied as an automatic scanner. It was developed by German company KUKA, model number KR10R1100 six WP. The scanner performs positioning of the transducer on the given distance from the controlled object.

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The proposed calibration technique is based on structural light method. This method is commonly used for 3-D reconstruction. It is based on the projection of vertical and horizontal lines at the surface of the object in a strict order. Digital projector is used as a light source for this purpose. At the same time as projection is made the received image should be captured by photo or video camera. Further data processing of the images enables to get points values of the controlled object.

The main feature of proposed non-contact calibration technique is implementation of a special calibration disk (see Fig.2). This disk is made in a shape of a triangle and is to be placed at the surface of the robotic manipulator. The measured points within the manipulator are located in the scanning area according to three corners of the disk. The results of scanning occur in a point cloud that can be used for the correlation between coordinate system of the robotic manipulator and an object (see Fig.3).

Due to mathematical calculations it is sufficient to have not less than 21 values of measured points. That has determined the choice of the calibration disk shape. Nine coordinates corresponding to the location of the triangle corners are known and the other nine coordinates can be easily determined in accordance to zero position. These values within three coordinates of the given point at the scanner flange allow to form a matrix of values. Necessary calculations can be made in accordance with [2] or can be realized by PCL libraries.

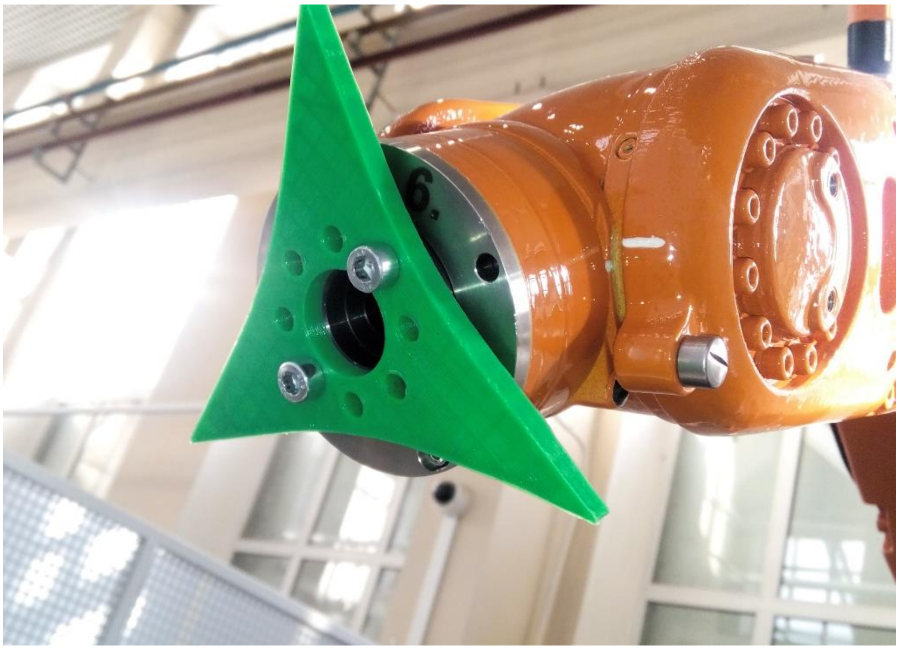

Figure 2. Implementation of the calibration disk

The results of testing with both contact and non-contact calibration methods demonstrated almost the same values [3].

Taking into account the fact that non-contact technique is simpler, less time consuming and more convenient we propose to apply this method for effective ultrasonic testing by a robotic scanner.

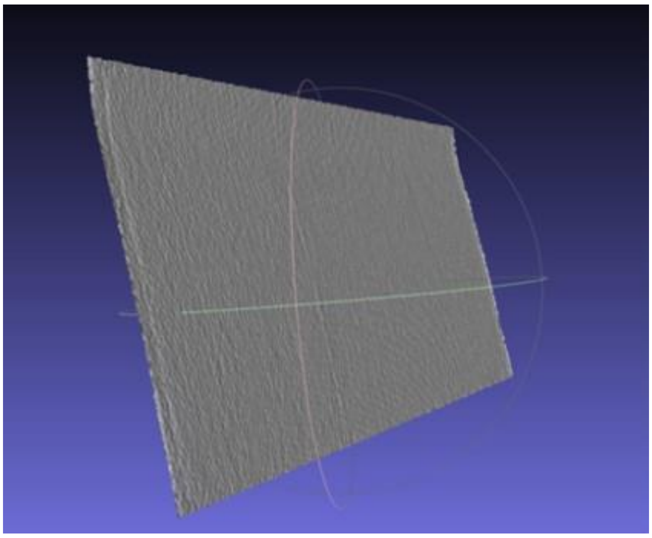

Figure 3. The point cloud of measured values

2.2. Generation of 3D CAD model

The other important aspect that effects total accuracy of testing is positioning of the scanner. It implies precise direction of the movement path. It is common to generate the path of the scanner according to the created model of an object. More accurate the model is, more useful it will be for setting the right path.

Three-dimensional reconstruction based on structured light techniques was chosen as approach for model creation. The experimental setup was described in the introduction of the second paragraph.

We propose a method of ultrasonic testing for complex shaped objects. These objects can have roughened surfaces or changed structure. Therefore, it is necessary to create a model of the object based on its condition at the time when inspection is required.

Moreover, it is evident that several defects might have different location depth. That is why it was suggested to define an object into several sectors according to depth. For example, in case there are no gates there might be the situation when signals from a defect interfere with the signal from the surface. Also, in order to improve the quality of 3-D reconstruction it was suggested to define a sector of the object by covering its surface with matte white coating.

Unlike calibration procedure the model generation requires a range set of values. The point cloud in accordance with the controlled object geometry is formed as a result of the scanning procedure.

Robotic ultrasound tomography system consists of the six-axes scanner KUKA. The special software developed by KUKA allows to set the path for the scanner if solid model of the object is applied. However, it is only possible to generate polygonal model by using a point cloud. The algorithm of scanner path setting allows implementation of T-splines or NURBS-surfaces. These splines are curves created by a complex mathematical formula that enable generation of solid models. Thus, it was suggested to transform point cloud into NURBS-surfaces.

The transformation procedure includes several steps:

1. Transformation of sparse point cloud into regular
2. Creation of the polygonal model by triangulation
3. Generation of the merged grid and its normalization
4. Division of the grid into T-splines
5. Transformation of T-splines into NURBS-surfaces

3. Experiment and results

A complex shaped composite object within 9 artificial defects is chosen as an experimental sample (See Fig. 4). There are three rows of three flat-bottom holes with diameter of 3, 6 and 9 mm. Each row is located at the different depth: 1/3; ½; 2/3 of wall thickness.

An experimental set up consists of a robotic system and single channel equipment with a frequency of 15 MHz (OLYMUS, 2-inch focus transducer).

This robotic system consists of ultrasound electronics unit, scanner and immersion tank described in paragraph 2. Ultrasound electronics was developed by I-Deal Technologies GMBH in collaboration with National Research Tomsk Polytechnic University.

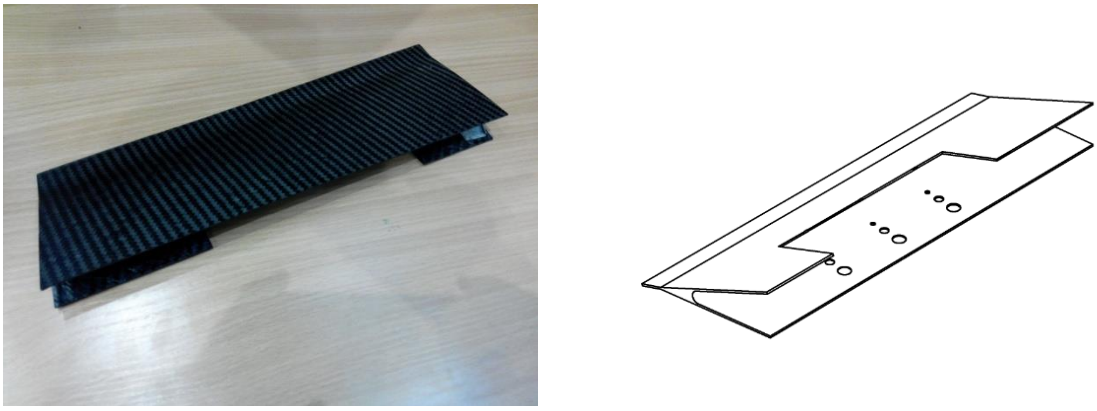

Figure 4. Experimental sample

The received results for the depth of 1/3 of the wall thickness are demonstrated in the Figure*. Three defects with different diameters are determined with high accuracy. Taking into account that the wall thickness is 1.8 mm we have estimated that the dead zone is about 0.5 mm which is rather small.

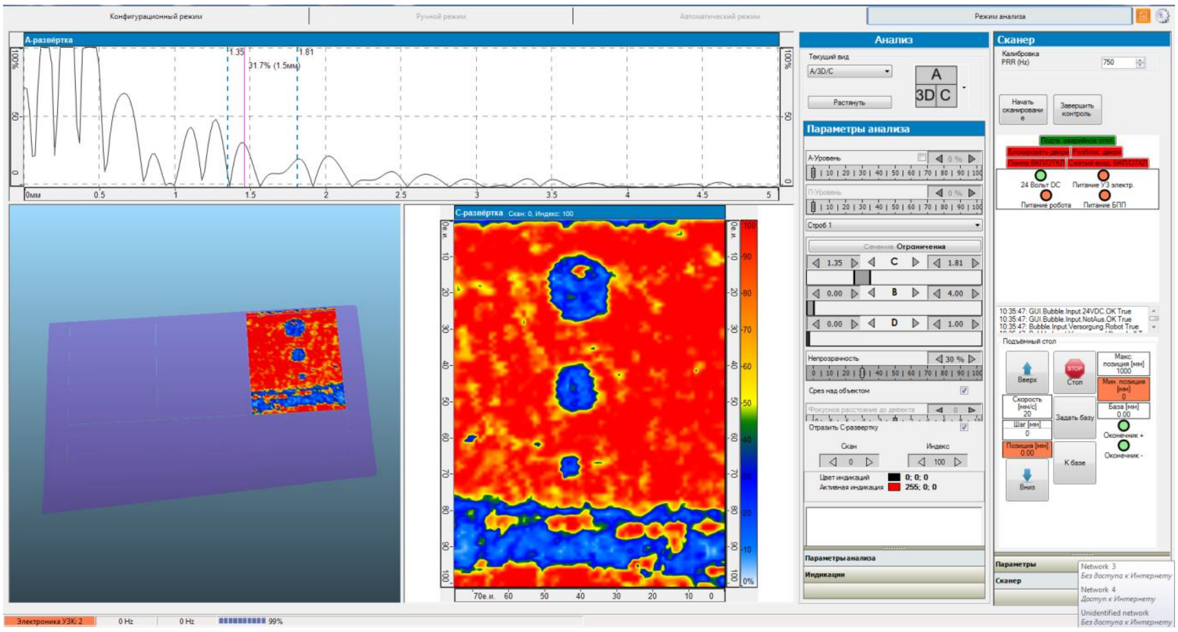

Figure 5. Experimental results

4. Conclusion

Accuracy of robotic ultrasonic testing depends not only on properties of the equipment but also on the precision of its calibration as well as on variance between the modeled path and real shape of the specimen. The path of the robotic scanner is defined according to the CAD-model of the object. The method proposed according to this study can be used for generating CAD-models of complex shaped objects. The object of any unknown shape can be controlled with implementation of the suggested optical reconstruction technique that provides accuracy about 150 μm.

Resulting from the experimental results it is evident that the proposed method provides effective nondestructive control of complex shaped carbon fiber composite materials. In fact, eight from nine defects in the experimental sample were determined unambiguously.

Furthermore, reliability of the received results also corresponds to the accuracy of calibration procedure. Non-contact calibration method proposed in this study is a rapid technique that allows to avoid human component and achieve more accurate positioning of the robotic scanner. We are currently extending this algorithm for implementation for objects of various shapes and materials.

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References

[1] Ashbya M, Smidmana M 2011 *Materials for nuclear power systems* p 20
[2] Borikov V, Galtseva O,Filippov G 2016 *IOP Conf. Ser.: Mat. Sc. and Eng.* **671** 12014
[3] Filippov G, Zhvyrblya V, Sharavina S, Salchak Y 2016 *MATEC Web. Conf.* (to be published)
[4] Spies M and Jager W 2003 *Ultrasonics* **41** 125
[5] Lanman D, Crispell D and Taubin G 2007 *3DIM* **3** 107
[6] Bulavinov A, Kröning M, Pudovikov S, Oster R, Hanke R, Hegemann U, Reddy K M and Venkat R S 2008 *International Symposium on NDT in Aerospace* p 21