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Non-contact calibration technique of ultrasound tomography system for complex shaped objects

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Abstract. Robot-assisted ultrasound tomography is an up-to-date technology that provides effective quality assurance of complex shaped objects. However, this method of control requires appropriate calibration of the equipment. At present, calibration is a difficult time-consuming procedure. This paper discusses novel approach – using non-contact calibration technique. The proposed method is based on the preliminary received 3-D reconstruction results. It is proved that non-contact calibration of ultrasound tomography system is more applicable and provides reliable measurement results.

1 Introduction

Nowadays ultrasound techniques are one of the most valuable methods of quality assurance. The main advantage of ultrasonic testing compared with other methods is ease of its implementation. It is also important that this type of control is applicable for the variety of materials, such metals and nonmetallic structures. Moreover, ultrasound method of control has high rate, low cost and is absolutely safe as compared to X-ray testing).

Ultrasonic testing techniques have improved significantly for the last several years. Usually it used to be manual instruments that were not able to create three-dimensional images of defects. At present, there are novel systems of ultrasound tomography that enable highly accurate reconstruction of the defects of a controlled object.

Recent development of additive technologies resulted into new requirements for ultrasonic systems. This is due to the fact that objects of control became more complex. For example, objects that are produced by 3-D printing technologies are usually not linear and have specific design. Hence, it is necessary to develop a quality assurance system for complex shaped objects.

2 Experimental Procedure

Robot-assisted ultrasound tomography system consists of six-axes scanner, immersion tank and electronic unit (see Fig.1). The major challenge for this type of testing systems is reliable estimation of relative position of the scanner and the controlled object. Today it can be determined by contact methods.

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An operator of the system is supposed to contact sides of the object with the special calibration tool. This procedure is time-consuming, has low accuracy and is not always possible due to the necessity of direct contact with an object.

Current algorithm of generation of the scanning path along the object of control consists of several steps. First, special instrument with a sharp nozzle is assembled at the scanner. Then, this instrument is placed at the particular points of the object for coordinates estimation (given to the length of the instrument). The determined coordinates are saved by the means of the software and compared with the chosen points at the object surface (typically they are angles). The whole process is to be carried out very accurately as the smallest mistake can lead to re-starting of calibration measurements.

Therefore, appliance of 3D- scanner system was proposed as a solution for the reason that it determines the coordinates of all points of an object.

The system consists of three main parts: instrumental unit; immersion tank and scanner.

The instrumental unit includes: PC, power supply, scanner controller, ultrasound electronics unit.

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.

Figure 1. Ultrasound tomography system.

Ultrasound electronics unit performs functions connected with transmitting and receiving acoustic signals, multiplexing of channels, digitizing of the signals, data transfer and processing (see Fig.2). 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 2. Ultrasound electronic unit.

It is sufficient to have only three points of both the known object and the object of control that fall inside the scanning area for the estimation of the controlled object in accordance with the scanner coordinate system.

A special calibration disk was designed for this purpose and then manufactured by 3-D printing (see Fig.3).

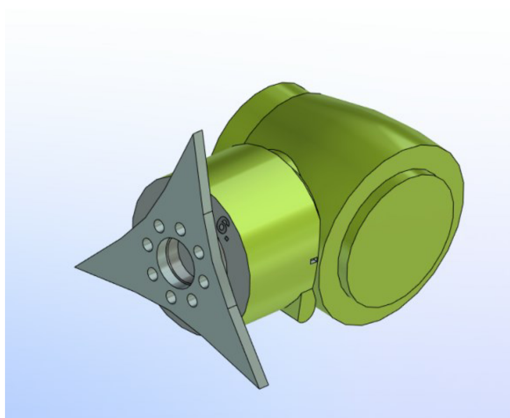

Figure 3. Calibration disk.

The developed calibration disk is rigidly fixed on the scanner flange. The scanner is guided to the controlled object in such a way that three angles of the disk and three points of the controlled object are located inside the scanning area. The point cloud is formed as a result of the scanning process (see Fig.4).

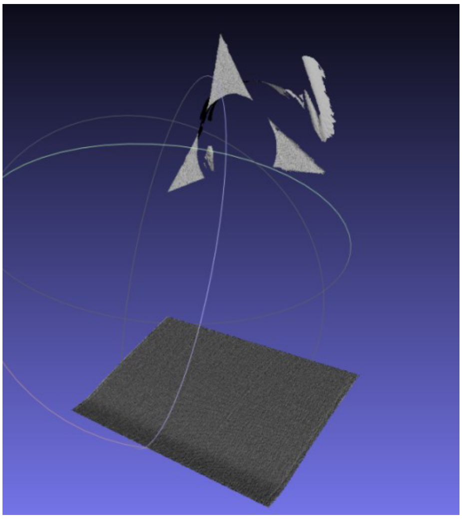

Figure 4. The point cloud.

It is possible to determine the location of an object in accordance with the scanner coordinate system by combination of the model of the object and the scanner with the point cloud. As a result, the matrix is formed. It provides position of the object regarding to the scanner location. Calculation can be made in accordance with [1] or can be realized by PCL libraries.

The transformation matrix for the given measurement was formed in accordance with [1]:

$$\begin{bmatrix} -0.853 & 0.070 & -0.515 & 1188.343 \\ -0.069 & -0.997 & -0.022 & 155.978 \\ -0.516 & 0.016 & 0.856 & 710.207 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The matrix formed as a result of contact calibration method is given below:

$$\begin{bmatrix} -0.875 & 0.064 & -0.611 & 1188.525 \\ -0.061 & -0.985 & -0.032 & 155.478 \\ -0.523 & 0.028 & 0.835 & 710.951 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Comparison of the matrixes reveal that both calibration methods provide the same result.

An object made of composite materials with artificial defects was chosen as an experimental sample (see Fig. 5). Ultrasound testing was chosen as the method of control [2].

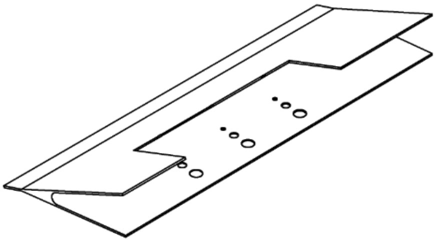

Figure 5. Carbon fiber experimental sample with artificial defects.

The ultrasound tomography system [3] was calibrated by contact and non-contact methods during the experiment (Figures 6 and 7). The most accurate results of control were supposed to determine the most efficient calibration method.

3 Conclusion

Comparison of the obtained results demonstrated that both calibration methods provide quality control assurance with the same level of accuracy. That is why the proposed method can be applied as a valid calibration technique for ultrasonic tomography systems. It can be used for nondestructive testing of the objects in critical industrial areas such as aerospace and aviation. Moreover, it is evident that the non-contact method of calibration is less time-consuming technique that enables effective nondestructive quality control.

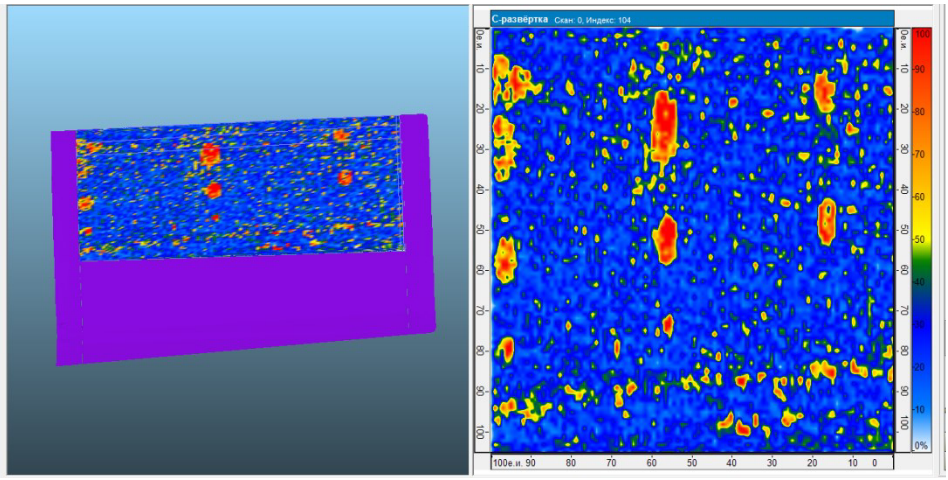

Figure 6. Results of control by contact calibrated system.

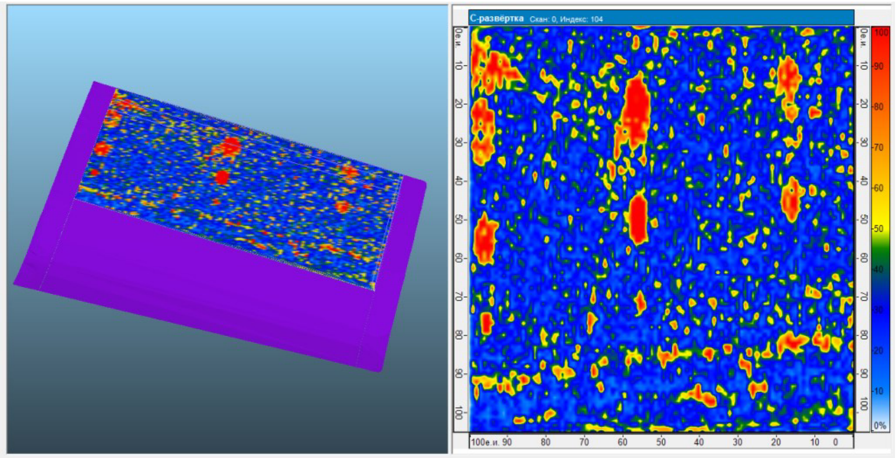

Figure 7. Results of control by non-contact calibrated system.

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