Development of an automated system for ultrasonic testing of products obtained by additive manufacturing processes

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Abstract. The authors conduct research on ultrasonic testing of products obtained by additive manufacturing processes. This article provides a diagram and a general view of the model of the developed ultrasonic system. The article contains a description of the object under study with simulated defects, as well as a scheme for its testing. As the results of the study, the article provides A-scans.

1. Introduction
Additive technologies, or 3D printing technologies, are some of the most advanced and fastest growing technologies in the industry. These technologies increase the mobility of production, allow you to replace many manufacturing processes, reduce the number of components in the product and, accordingly, the number of assembly, welding, gluing operations, reduce the complexity of manufacturing, save raw materials and minimize waste, as well as reduce the weight of products and the possibility of manufacturing single products. Additive technologies include methods such as binder jetting, material extrusion, sheet lamination, and vat photopolymerization. One of the methods of additive manufacturing is Selective Laser Melding (SLM, powder bed fusion) – a synthesis process on a substrate, performed to produce parts from powder materials using one or more lasers for selective sintering or fusion of particles on the surface, pre-applied layer of powder material, layer by layer, in a closed chamber [1]. The SLM technology makes it possible to create new products and improve the existing ones for all industries, including aircraft, rocket, ship, auto and engine manufacturing, tool manufacturing, power engineering, etc.

2. Relevance of the topic
However, the use of these technologies does not exclude the formation of defects. The most characteristic for additive processes are defects associated with discontinuity, such as pores, cracks, non-metallic inclusions, non-fusion – these are defects that can be detected by ultrasonic inspection methods in accordance with [2]. Defects such as general and local displacement of the layers, lack of geometric accuracy in the arrangement of the layers, and inconsistency with the required roughness parameters also occur.

Also a characteristic feature of additive manufacturing processes associated with layer-by-layer deposition of material is a rather high surface roughness that impedes the ultrasonic testing with high
sensitivity upon contact input of ultrasonic waves [3]. At the same time, for additive technologies, the issue of product quality control is currently poorly developed. Thus, to ensure the introduction of new manufacturing technologies in order to improve product quality, it is necessary to create appropriate methods, techniques and means of quality control [4].

3. Development of an ultrasound system

To control the quality of products manufactured by the methods of additive manufacturing processes, it is proposed to use ultrasonic testing and obtain two-dimensional images of the sections of the test object using the shadow and echo methods. In this case, to ensure stable acoustic contact, an immersion method of ultrasonic testing is used.

To solve this problem, an ultrasonic system was developed and manufactured (figure 1), including an automated installation for moving and positioning the test object and ultrasonic transducers, a control unit, an ultrasonic two-channel flaw detector and a set of ultrasonic piezoelectric transducers (with different operating frequencies and focusing), as well as specialized software.

The developed automated installation for moving and positioning the test object and ultrasonic transducers as part of the developed ultrasonic complex system provides:

- ultrasonic testing by immersion method by the shadow and echo method;
- scanning of the object under test with a given step and speed;
- precision positioning of the probes relative to the test object and the coaxial arrangement of the probes (transmitter-receiver) during shadow control.

A diagram of an automated installation for moving and positioning the object under test and ultrasonic transducers as part of the developed ultrasonic system is presented in figure 2.
Figure 2. Scheme of an automated installation for moving and positioning the object under test and ultrasonic transducers as part of an ultrasonic system:
1 – immersion bath; 2 – drive horizontal movement; 3 – drive vertical movement; 4 – engine rotation of the control object; 5 – probe; 6 – holder transducers in the axial direction of sounding; 7 – holder of converters in the radial direction of sounding; 8 – object of control; 9 – holder of the object of control; 10 – rotation drive; 11 – thrust bearings; 12 – transmission of rotation.

The developed ultrasonic system provides:
- automated control of products having a complex geometric shape;
- objectivity of control by eliminating the human factor;
- high speed of control;
- coaxial fixation of a pair of probes and precise positioning relative to the test object, stable acoustic contact, which ensures complete control of the product;
- the ability to control products with a roughness of up to $R_z = 160$.

The ultrasonic system has overall dimensions of $1050 \times 824 \times 630$ mm and allows you to control the monitoring objects with a diameter of up to 250 mm and a height of up to 85 mm. The ultrasonic system provides rotation of the test object around its axis with a positioning accuracy of 50 microns. Converters have 3 or 4 degrees of freedom depending on the control circuit.

4. Object of research and testing scheme
Using an ultrasound system, studies were conducted on a sample made using SLM technology with artificially embedded defects. The object of research was a turbine wheel having complex geometry and periodic structure. Reflectors of the type flat-bottomed and lateral cylindrical holes (with diameters from 0.8 to 5.0 mm) with different orientations, as well as cuts, were embedded in the manufactured sample (figure 3).

Figure 4 shows the scanning scheme of the fabricated sample. The control was carried out by the shadow method in the axial direction (figure 4 (a)), the shadow method in the radial direction (figure 4 (b)), and the echo method from the outside (figure 4 (c)).
Figure 3. Appearance of the object under test (bottom view): 1 – through hole $\varnothing 0.8\text{mm}$; 2 – propyl; 3 – lateral cylindrical hole $\varnothing 5\text{mm}$ on the outer belt, 4 – lateral cylindrical hole $\varnothing 5\text{mm}$ on the outer belt.

Figure 4. Sample testing schemes: (a) the shadow method in the axial direction, (b) the shadow method in the radial direction, (c) the echo method in the radial direction.
During the testing, immersion unfocused probes with a central operating frequency of 5 MHz and a piezoelectric plate diameter of 5 mm were used.

5. Results
As a result of scanning the sample in accordance with the proposed control schemes (figure 4), all inherent defects were identified. Figure 5 shows examples of A-scans with detected defects (figure 5 (a)) and A-scans in luminance representation, connected into one continuous image (figure 5(b)), in which the signal on the defect-free part of the product is clearly visible (solid red line in figure 5 (b)) and signals of lower amplitude or their absence in areas with embedded defects.

![A-scans with detected defects](image.png)

**Figure 5.** (a) A-scans of the belt of the test sample; (b) the addition of A-scans of the belt of the test sample obtained by the shadow method in the radial direction: 1 – through hole Ø0.8 mm; 2 – propyl; 3, 4 – lateral cylindrical holes Ø5mm (filled with air) on the outer and inner OK belt, respectively.

As a result of the experimental testing, the possibility of identifying flat-bottomed and lateral cylindrical holes with a diameter of 0.8 mm or more was confirmed.
6. Conclusion
Thus, an ultrasound system was developed and manufactured that provides:

- fixing, positioning (centering) and rotation of the object under test around the axis by 360°;
- precise positioning of the transducers relative to the object under test;
- vertical and horizontal scanning of the object under test with a given step and scanning speed by shadow and echo methods.

The system allows you to perform automated ultrasonic quality control of products obtained by the methods of additive manufacturing processes.

The experimental testing of the ultrasonic system showed the possibility of monitoring products manufactured using SLM technologies with a roughness of up to Rz = 160 and the possibility of detecting defects in them from 0.8 mm in size. With a decrease in roughness (rough surface treatment), the sensitivity of ultrasonic testing can be increased.

As a result of the research, the effectiveness of applying this control method to products obtained by the methods of additive-manufacturing processes was confirmed.

In the future, it is planned to finalize the ultrasound system in order to ensure the possibility of scanning the objects under test at different angles to the surface, as well as to increase the sensitivity of the control, in particular the detection of internal pores and cracks.

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