# LASER-ULTRASOUND DIAGNOSTICS OF PLASTIC PRODUCTS MANUFACTURED BY LASER STEREOLITHOGRAPHY

A.A. Karabutov[1], M.M. Novikov[1] *

[1] Institute on Laser and Information Technologies of RAS –
branch Research Centre Crystallography and Photonics RAS, Shatura, Russia – aak@optoacoustic.ru, novikov@rambler.ru

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**ABSTRACT:**

This paper discusses the application of methods of non-destructive testing and flaw detection of plastic products manufactured by additive technologies. The modern development of additive technologies associated with the active transition from the manufacture of prototypes and test samples to the manufacture of functional products increases the requirements for improving the quality of manufacturing and conducting non-destructive diagnostics of finished products, including plastic materials. The overall productivity of the production process can be increased by increasing the yield due to a decrease in the number of defects, which is ensured by process control and the quality of finished products. The method of laser-ultrasound diagnostics allows monitoring and flaw detection of products made of different materials with good spatial resolution, which is not always possible, for example, by tomographic scanning. Thus, the main purpose of this work is to evaluate the possibility of using laser-ultrasonic methods to detect potential defects and to track the impact of the additive manufacturing process on the quality of plastic products.

## 1. INTRODUCTION

The development of laser technology, computer systems for three-dimensional modeling, the development of special materials and equipment made it possible to directly manufacture a three-dimensional computer model with any geometric shape by adding material. Now these technologies have stepped far forward, having found many applications in production, approaching, in addition to making prototypes and copies, the creation of full-fledged functional models. Therefore, at the moment they have received the general name "additive manufacturing". An analysis of the current state of additive technologies based on the photopolymerization process (Schmidleithner, 2018) shows that they are not only successfully developing, mastering new price segments, but also developing new promising materials and original applications.

The development of new photopolymer compositions that provide high functional properties of products manufactured by laser stereolithography methods is of great importance for the development of additive manufacturing. The main advantage of this technology is the ability to quickly create products and build models of complex shapes with high accuracy. After the introduction of this technology in 1981 (Jacobs, 1992), significant progress was made in the development of photopolymer compositions for the creation of products with high physicochemical characteristics (Halloran, 2016). To increase the productivity of the production process and improve the quality of manufactured products, the development of contactless methods for detecting potential defects and tracking the impact of the technological process on the quality of the final product is required. In (Morozov, 2016), the use of magnetic resonance imaging (MRI) for monitoring and studying the output quality of plastic models based on acrylate made using stereolithography was presented. The influence of the assembly parameters and the wet environment on the uniformity of the sample, the distribution of the crosslinking density, stability and the formation of defects was studied. Various types of defects in the samples were detected and classified; some defects arose due to local violations of the continuity of the matrix (partial solidification of the cured resin inside the polymer or the formation of bubbles), while other defects were detected in the form of bulk layering. This paper discusses the use of laser ultrasound tomography for the study of plastic models obtained by laser stereolithography to obtain more accurate data on the geometry of defects.

### 1.1 Laser stereolithography and laser ultrasound tomography

Laser stereolithography is one of the additive technologies. In this case, a three-dimensional object is formed in layers by reproducing each layer on the surface of a liquid resin using laser radiation, usually in the ultraviolet range. The liquid resin under the action of laser radiation polymerizes, forming a thin polymer film. The transition to the next layer is carried out by immersing the platform on which the object is placed in a container with liquid resin to a depth equal to the thickness of the next layer. When polymerizing the next layer, it is glued to the previous one, which ensures the rigidity of the entire product. The formation of the layer is carried out by reproducing the external and internal contours and filling the space between them with the appropriate shading. (Vnuk, 2021). Laser ultrasound tomography was used in this work to diagnose possible defects associated with the technology of forming bulk plastic products by laser stereolithography.

The laser ultrasonic (LU) diagnostic method is based on the generation of sound waves by a laser pulse. This pulse is absorbed in the surface layer of the object under study or in a special material called an optical-acoustic (OA) generator. The

* Corresponding author

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LU method uses a short (usually <10 ns) laser pulse to generate a short (<100 ns) and broadband (1-9 MHz) acoustic probing pulse due to the optical-acoustic effect (Bychkov, 2018). The LU method is efficient and fast-acting, since a laser pulse is used to generate a probing ultrasonic signal, and the bandwidth of the probing pulse can be quite wide (from units to tens of MHz). At the same time, ultrasonic transducers can be optimized for broadband reception and better acoustic communication, since they are not used to generate ultrasound.. This makes it possible to conduct broadband ultrasonic monitoring of objects and effectively separate the generation and detection of ultrasonic signals to increase the signal-to-noise ratio (Bychkov 2017). The appearance of focused piezoelectric antenna arrays and the active development of computer technology significantly expand the possibilities of laser-ultrasonic (LU) tomography of the internal structure of rocks, composite materials, biological and other heterogeneous media (Beard, 2011, Chen, 2017, Schellenberg, 2018).

# 2. MATERIALS AND METHODS

## 2.1 Test Object

For the test object, a model of a thin disk with a diameter of 40 mm and a thickness of 2.5 mm was used, the shape of the disk has minimal deformations associated with volumetric shrinkage, and the small thickness allows in one experiment to study the entire structure of the model, the upper and lower layers of the object formation (Figure 1).

**Figure 1**. Photo of the control object.

Technological style of object formation.

```
;Hatching step by X Y
h.step=0.25 0.25
;Offset cycle X Y
h.Shift step=2 2
;pseudo Equidistant h.pseudoEquid= 0.05
;Hatching indent
x.indent=0.03
;Hatching order (Mode): 0/1/2/3 = X/Y/XY/X-Y
h. order=2
;Through-layer inversion of the hatching direction 1/0 - yes/no
sec.Version=1
;Hatching parameters of the upper and lower planes
;Hatching step by X Y
hU.step=0.15 0.15
;Offset cycle X Y
hU.shift step=2 2
;;pseudo Equidistant
hU.pseudoEquid=0.05
; Hatching indent
xy.indent=0.03
;Hatching order (Mode): 0/1/2/3 = X/Y/XY/X-Y
hU.order=3.
```

The samples were made in layers of 150mkm, the total number of layers is 17, the bottom plane polymerization depth is 180mkm, the inner hatching is 120mkm, the upper plane is 160mkm. The group of samples included models with different laser delay times per point, marked respectively 1 sample – 2 points, 2 sample – 3 points, 3 sample - 4 points.

## 2.2 EXPERIMENTAL SETUP

The experimental setup contains an Nd:YAG laser with Q-factor modulation (LQ 129, Belarus), 1064 nm, 10ns, pulse repetition rate of 10 Hz and pulse energy of 10 mJ; laser radiation delivery system including optical fiber; receiving antenna, amplifier of received electrical signals; a high-speed multichannel system for collecting and processing experimental data based on the NI FlexRIO architecture, containing a preprecision analog-to-digital converter (sampling frequency 50 Mhz) and providing the translation of electrical signals from piezoelectric receiving elements into digital form, their storage, averaging and transmission over a high-speed communication line to a personal computer; a data processing system including a personal computer. Figure 2 shows the piezoelectric antenna and the test object in a bath of water.

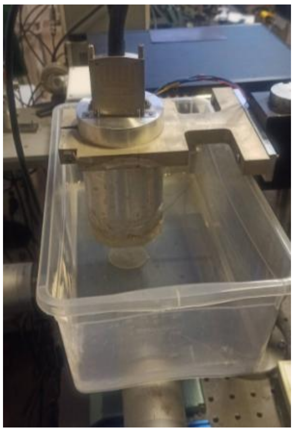


**Figure 2**. Experimental Setup.

# 3. FLAW DETECTION OF PLASTIC DISKS

The group of samples included models with different laser delay time per point, which corresponds to a different dose of illumination of the liquid resin. The results of structroscopy are a set of slices along the XZ, YZ and XY planes. The analysis of the scan data is carried out in layers in the ADC View program. Figure 3 shows the program tab with the results of sample control No. 1 with slices passing through the center of the sample: windows 1-3 show slices XY, YZ and XZ, respectively, window 4 is the filter setting window, window 5 shows the signal registered at the surface point with the X and Y coordinates selected in window 1 by the crosshair red markers.

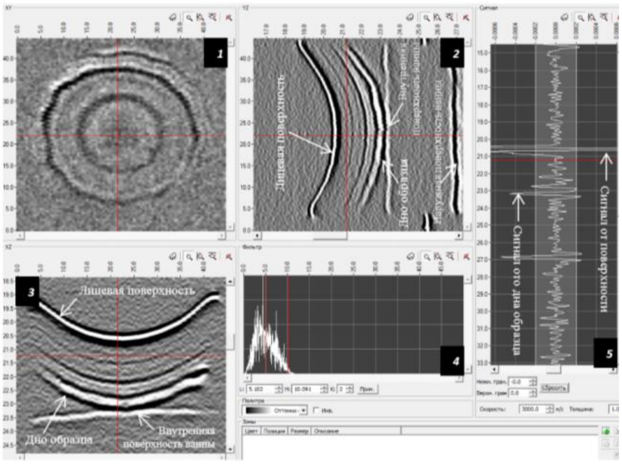


**Figure 3**. The results of scanning sample No. 1 in the CLUE-AutoScan program are:
1 – a window with a slice along the XY axes,
2 – a window with a slice along the YZ axes,
3 – a window with a slice along the XZ axes,
4 – a filter setting window,
5 – a signal selected in window 1 with a crosshair.

The front surface of the test sample is represented by a bright white line, the reflection from the free bottom surface (as well as from any discontinuity) is represented by an intensely dark line. In Figure 3, the front surface of the sample and its bottom are marked, as well as the corresponding recorded signals are marked in window 5. In the central part of the sample, the internal structure is well traced: 7÷8 layers can be counted. The greater the difference in the impedances of neighboring layers, the more noticeable the boundary between them. In windows 1-3, the borders between layers are displayed with dark lines. It can be seen that the boundaries of a more intensely dark color are observed near the bottom surface (the bottom layer itself is displayed with a bright white stripe), which indicates that the bottom layers are much more rigid compared to the rest. The location of the features in depth is recalculated based on the speed of ultrasound propagation in the material and corresponds to real values in mm. It can be seen with the naked eye that the sample is not flat. Any irregularities in the periodicity of the pattern on the slices indicate the presence of inhomogeneities of the internal structure.
Figure 4 shows the test results with slices passing through the detected inhomogeneities of the internal structure. These features are displayed in window 1 by dark spots, in windows 2 and 3 by the subsidence of the signal from the boundary between the bottom layers (marked in all windows with red arrows). Window 5 shows that the signal from the inhomogeneity exceeds the amplitude of the bottom signal (which, in turn, is weakened compared to the signal shown in Figure 3), and thus this feature is most likely a discontinuity.

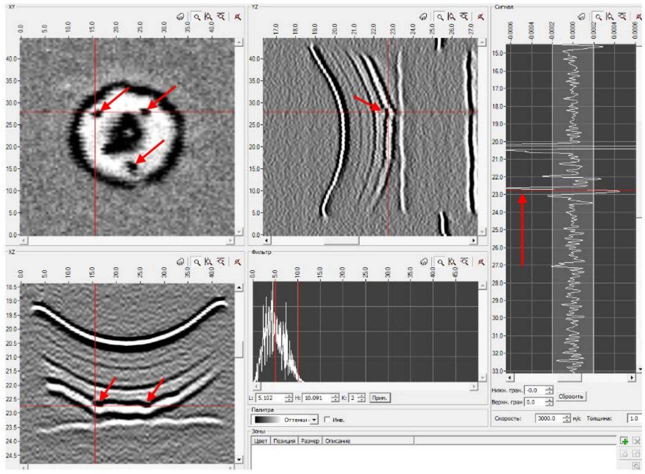


**Figure 4.** Results of scanning sample No. 1 with slices passing through the discontinuity.

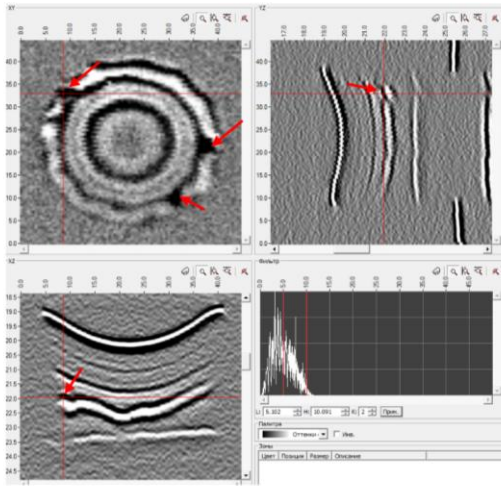
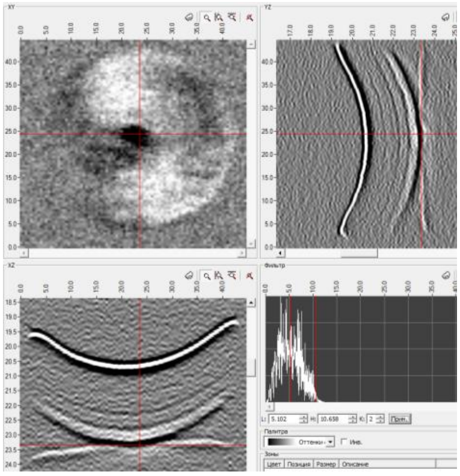
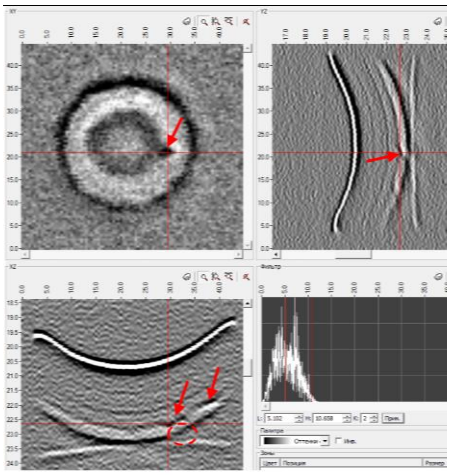


**Figure 5**. Results of scanning sample No. 1 with slices passing through the feature of the internal structure.

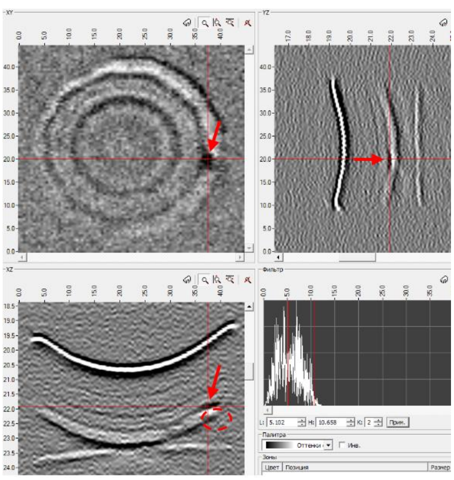
Figure 5 shows another set of slices passing through the inhomogeneities of the internal structure of sample No. 1. The signal from the boundary of the bottom layer "subsides" (marked with red arrows on the XZ and YZ sections, the same in Figure 3), which indicates the inhomogeneity of the internal structure in the volume of the penultimate layer. The signal subsidence is marked in the figure with red arrows. The bottom line repeats the profile of the aforementioned boundary between the layers. Despite the detected features, the bottom signal is observed throughout the entire volume of the sample. These features are discontinuities and are located on the border between the bottom layers. There are quite a lot of features of this type of structure in the sample.
Figure 6 shows the results of scanning sample No. 2.



a) A set of slices passing through the center of the sample. A homogeneous internal structure is visible. The boundaries between the layers are not as noticeable as in the previous disk. However, the bottom layer is slightly more rigid compared to the other layers.



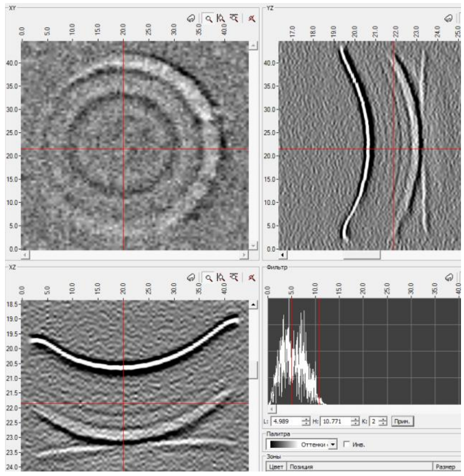
b) A set of slices passing through a feature of the internal structure, which is a discontinuity (marked with red arrows). The bottom signal "under" the feature is absent or severely weakened. The discontinuity is located between the bottom layers.



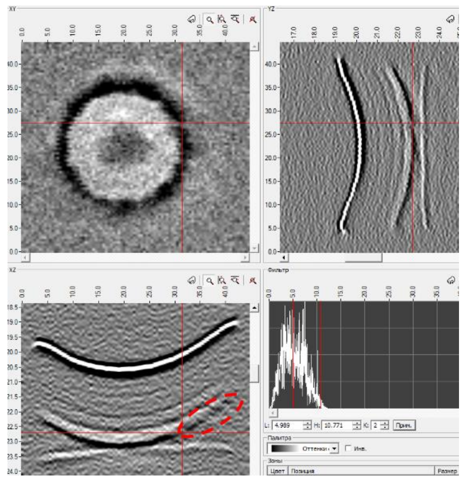
c) A set of slices passing through a feature of the internal structure, which is a discontinuity (marked with red arrows). The bottom signal "under" the feature is greatly weakened. The discontinuity is located between the bottom layers on the periphery of the sample.

**Figure 6**. Results of scanning sample No. 2 with sections: a) passing through the center of the sample, b) and c) passing through the features of the internal structure.

Sample No. 2 has a fairly homogeneous structure, there are several features of the "discontinuity" type.
Figure 7 shows the results of scanning sample No. 3.



a) A set of slices passing through the center of the sample. A homogeneous internal structure is visible. The boundaries between the layers are not as noticeable as in sample No. 1. The bottom layer is slightly more rigid compared to the other layers.



b) A set of slices passing through the periphery of the sample. The bottom signal is weakened, sometimes disappears. Most likely, this is due to increased scattering on the inhomogeneities of the bottom layer, since no discontinuities were detected.

**Figure 7.** Scan results of sample No. 3 with slices: a) passing through the center of the sample, b) passing through the periphery of the disk.

Sample No. 3 has a fairly homogeneous structure, no features of the "discontinuity" type were found.

## 4. CONCLUSION

The internal structure of plastic disks was controlled by laser-ultrasonic method. The sample group included models with different delay times per point. The work carried out showed the possibility of flaw detection of plastic models made by laser stereolithography using laser acoustic tomography. Conducting additional research will allow us to obtain accurate geometric dimensions and to qualify the types of inhomogeneities, which will allow us to choose the optimal parameters of the technological process to obtain better products.
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